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BUILDING STONES AND CLAYS:

THEIR ORIGIN, CHARACTERS
AND EXAMINATION

BY

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To

PROFESSOR T. NELSON DALE

Whose work on slates and granites has at last given
American economic geology adequate
representation in that field.

Cm.

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PREFACE

THE present volume may in some sense be considered as an outgrowth of the author's previous work on cementing materials, for it deals with natural materials which are closely related, either as constituents or as competitors, to the manufactured products therein discussed.

It may be noted that little space has been devoted to a description of the local distribution of building stones and clays. The inclusion of such data, relative to products which are naturally so common and so widely distributed, tends to convert a general treatise into a mere directory of the quarry and clay product industries. The extensive reference lists which are presented, however, will serve to point out where information regarding the stone or clays of any particular state may be found. Attention should also be directed to the chapters relative to the examination and valuation of clay and stone properties. So far as known to the writer, most of the material therein presented has not been touched upon in earlier works on these subjects.

EDWIN C. ECKEL.

WASHINGTON, D. C.
January 13, 1912.

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BUILDING STONES AND CLAYS

PART I. BUILDING STONES.

CHAPTER I.

THE ORIGIN AND STRUCTURE OF ROCKS.

The Engineering Applications of Geology. — The geology of a region bears upon the work of the engineer in three different ways, through its influence, respectively, on the topography, structure and materials of the given area.

(1) The topography of the district, on which depends the location of both drainage lines and transportation routes, is directly related to the geologic history of the area.

(2) The underground structure determines the accessibility of industrially valuable mineral deposits, as well as the occurrence of underground water supplies.

(3) The rocks and minerals present in any given area will usually contribute, either directly or indirectly, to the supply of materials available for structural work, and for other purposes.

With these facts in view, it is evident that the relations to engineering of structural and economic geology are very intimate. In the present volume, which deals with two of the more important groups of structural materials used by the engineer, we are concerned chiefly with a study of the manner in which certain raw materials have been made available for use. Before, however, taking up these particular raw materials in detail, it will be well to briefly summarize the main features of what may for convenience be termed Engineering Geology.

Outline of Earth History. — For our present purposes it is sufficiently accurate to assume that the earth, in the earliest stage of its history requiring consideration, was a fused mass, of approximately spherical shape, cooling slowly from the exterior inwards, and surrounded by an envelope of gases. When the cooling had progressed far enough, the earth's exterior and

center solidified gradually — a surface or crust of *igneous* rocks being formed — while local differences in the rate of cooling caused irregularities in this surface. Combinations of the cooling gases caused the precipitation of water, in the form of rain; and with the action of the first surface water began the formation of the *sedimentary* rocks. The fallen rain gathered in slight depressions of the crust to form the earliest streams and rivers; and followed these courses to deeper depressions which formed the earliest seas and oceans. In its course the water, whether raindrop or stream, carried off small portions of the rocks it encountered, transporting them either mechanically or in solution, and depositing them finally as sediments. This process has continued to the present day, a steady supply of detritus being carried to the seas; and it is obvious that some counterbalancing process must act to prevent all the lands being worn down to sea level. This compensatory action is evidenced by the gradual depression, at intervals, of portions of the sea bottom (overloaded with deposits of sediment) and the consequent *relative* elevation of the land areas. The process is therefore continuous, forming a regular three-phase cycle, the phases being (1) erosion of high lands by running water; (2) deposition of the resulting detritus on the sea bottom; (3) overloading and consequent depression of parts of the sea bottom with a corresponding relative elevation of the land and the recommencement of erosion.

At intervals in the earth's history these regular cyclical changes have been aided or retarded by less regular occurrences. Masses of fused rock have been forced up from the interior to cool at or near the surface; heat and pressure have caused great changes in deeply buried rock masses; minor movements in the crust have caused folds, faults and joints in the rock series; and once at least temperature changes have caused a *glacial period* in the temperate zone. So far as these phenomena concern the engineer they will be discussed in later paragraphs.

Life was, so far as known, existent before the formation of our earliest identified sedimentary rocks. Through the following ages it has, however, greatly changed in form and type; and this gradual evolution in living organisms aids in determining the relative ages of the rocks in which their fossil remains are now inclosed.

Relative Age of Rocks.— The geologist, confronted with a finished product—a given tract of country—endeavors to work out its history. Usually the first step in this direction will be to map the areas covered by different kinds of rock, but along with this areal mapping he must carry on studies to determine the relative age of the various rock formations which occur within the limits of the tract under consideration. In doing this the following criteria are of most service.

(a) *Superposition.*— Since sedimentary rocks are surface deposits, it is obvious that of two series of sedimentary rocks, the overlying series must be the younger, provided that no serious earth movements have altered their relative position since they were deposited.

(b) *Contained Fragments.*— If one rock formation contains pebbles or other fragments of material evidently derived from another formation, the fragment-containing bed must have been formed after the other had been deposited.

(c) *Contained Fossils.*— This, which is usually the most exact and positive criterion of all, is not immediately evident like the preceding two. In the progress of geologic science, it has been determined that beds of certain age are characterized by certain assemblages of fossil remains. Comparison of the fossils found in the beds of the area under study with those found in some area where the succession is already known, will therefore fix the relative position and age of the series under study.

Geologic Chronology.— By the careful application of the criteria briefly described in the preceding section, a fairly complete geologic chronology has been gradually worked out to cover the whole extent of earth history. For convenience of reference and comparison, all of geologic time is primarily divided into twelve *periods*, which in turn are subdivided into *epochs*. Still more minute subdivisions are *stages*, while the final unit of division is the *formation*.

This system of subdivision gives a series of time intervals which, taken together, cover all geologic history. The names of the periods are given below in order downward from the most recent (Quaternary) to the earliest (Archæan). In a few cases the subdivisions into epochs are also given.

	<i>Period</i>	<i>Epoch</i>
Cenozoic	Quaternary	{ Recent Pleistocene
	Tertiary	{ Pliocene Miocene Oligocene Eocene
Mesozoic	Cretaceous	
	Jurassic	
	Triassic	
Paleozoic	Carboniferous	{ Permian Pennsylvanian or Coal Measures Mississippian or Subcarboniferous
	Devonian	
	Silurian	
	Ordovician	
	Cambrian	
Pre-Cambrian	Algonkian	
	Archæan	

To the engineer the determination of the geologic age of the rocks of any given district is rarely a matter of importance, except in so far as geologic age may affect the character of the mineral products. It would be folly, for example, to expect to find important workable deposits of coal in rocks older than the Carboniferous period — but that is about the only valuable *general* statement that can be made. In any particular small area, of course, a relation between age and material is more common. The valuable “cement rock” of the Lehigh district of Pennsylvania, for example, occurs in that region only in beds of one particular geologic age, and it would be useless to search for it in rocks of other periods. Another case in point is the red or fossil iron ore, so important to the southern iron industry. This occurs in the eastern United States only in rocks of Clinton age, and the presence or absence of the ore on any particular property can therefore be inferred on purely geologic grounds. In Luxembourg, however, an entirely similar ore occurs in rocks of much later age — so that it is evident that such a generalization is safe only within rather close geographic limits.

The Geologic Viewpoint. — It is not at all difficult for an engineer, confronted with some semi-geologic problem, to master in a short time the principal geologic facts to which he must give consideration. That is merely a matter of application to a rather interesting study. What is difficult, however, is for him to learn to look at these facts from what may be termed the geologic viewpoint.

To judge from published reports on water-supply problems and other work involving engineering geology, the tendency is to assume unconsciously that in considering geologic facts it is useless to apply the same type and closeness of reasoning which are essential to the solution of purely engineering problems. The effect of this mistaken attitude is that the engineer too often is inclined to invoke forces and agencies totally unknown to engineering practice in order to aid in solving a geologic problem; so that the finished report is frequently a curious mixture of clear observation and erroneous interpretation.

In considering this matter the engineer will avoid many serious misinterpretations of facts if he bears in mind that:—

(a) Geologic occurrences are to be explained by reference to the same physical forces which are now in operation — running water, winds, frost, terrestrial heat, etc.

(b) These forces have, on the whole, always been of about the same degree of intensity; the one prominent exception being the extension, during the glacial period, of intense ice action into the temperate zone.

(c) Changes in the earth's surface — whether of coast line, relief, or drainage — have been almost invariably brought about with extreme slowness.

(d) Gorges, canyons, mountain ranges and other striking physical features are therefore due almost always to the long continued action of ordinary familiar physical forces, and not to sudden and violent "upheavals," "volcanic outbursts" or other "convulsions of nature."

Kinds of Rocks. — Rocks are classified, according to origin, in one of two groups: (1) *igneous*, or (2) *sedimentary*. In by far the majority of cases there is no difficulty in determining the group in which any given rock should be placed; but at times the decision is more difficult and, in some cases, impossible.

(1) The *igneous* rocks are those which have been formed by the cooling of fused material. The original crust of the earth was of course formed entirely of igneous rocks, but it is highly improbable that any of this original crust is now exposed at the earth's surface. The igneous rocks with which we have to deal are of later origin, being derived from molten material which at different periods has been forced up through and into other rocks. In most cases this molten rock did not reach the surface

while fused, but cooled and solidified slowly while covered by thick masses of overlying material, and is now exposed to view owing to the slow removal of this covering.

(2) The *sedimentary* rocks are those derived from the decay of preëxisting strata, the material so obtained being carried (usually by water) in suspension or solution to some point where it is redeposited as a bed of sand, clay or limestone. Subsequently this loosely deposited material may become consolidated and hardened by pressure or other agencies, the result being the formation of sandstones, shales and slates from the original unconsolidated beds of sand and clay.

In the later chapters of this volume, which deal respectively with the igneous rocks and the sedimentary rocks, further data will be presented on the characters, origin and subclassification of each of these groups.

Metamorphism of Rocks. — All rocks are more or less changed or *metamorphosed* from the condition in which they were first deposited (in the case of sedimentary rocks) or in which they first cooled from fusion (in the case of igneous rocks). The changes are due to the action of heat, pressure and chemical agencies; and the effects may appear in changes of either the physical structure of the rock, its texture or its chemical composition.

As has been said, all rocks have suffered such changes or metamorphism to a greater or lesser extent, but the term *metamorphic rocks* is restricted properly to the rocks in which the changes have gone so far as to produce very marked alterations, sometimes entirely obliterating the original structure, and at times rendering it difficult or even impossible to decide whether the original rock was of sedimentary or of igneous origin.

Conventional Symbols for Rock Classes. — In representing the different classes of rocks on geologic cross sections, it is often necessary to adopt different symbols or patterns so as to distinguish between igneous rocks, shales, limestones, etc. Though these symbols are purely conventional, there is a great advantage in having the same symbols adopted by every one for the same rocks, and considerable uniformity in this regard can now be seen in the publications of the various geological surveys.

In Fig. 1, the patterns for the different classes of rocks by the United States Geological Survey are shown.

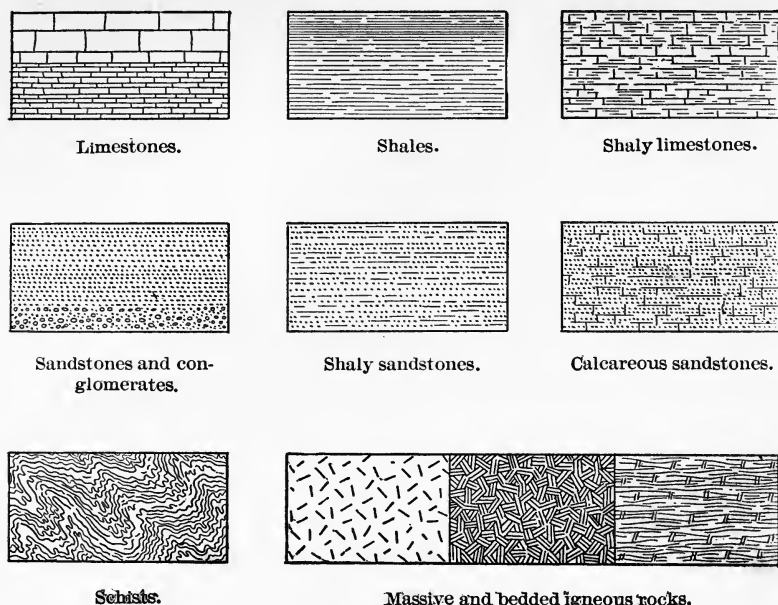


Fig. 1. — Conventional symbols for kinds of rock.

Chemical Relationship of the Classes of Rocks. — A feature of considerable economic and scientific interest appears to have been overlooked by geologists as well as by engineers. This is the relationship which exists between the chemical composition of the various classes of rocks. It is well brought out in the following table, which was prepared by combining data published by Professor F. W. Clarke and by the present writer.

It will be seen that this table gives average analyses of large series of different rock groups, and the averages may therefore be considered to fairly represent the mean composition of these groups. Examination of the table shows that the average igneous rock is closely similar in composition to the average shale and the average slate. In other words, the shales and slates are made up of fine particles of the same materials which occur in the igneous rocks, and in about the same proportions. Evidently little chemical sorting or segregation took place during the formation of shales and slates. With regard to the sandstones and limestones the case is very different. Here there has been

a great deal of separation, resulting in the deposition of almost pure silica in the case of sandstones and of lime carbonate in limestones.

TABLE 1.—AVERAGE ANALYSES OF VARIOUS CLASSES OF ROCKS.

	830 Igneous rocks.	78 Shales.	36 Slates.	371 Sandstones.	345 Limestones
Silica (SiO_2).....	59.71	58.38	60.64	84.86	5.19
Alumina (Al_2O_3) *.....	16.01	16.12	18.05	6.37	0.87
Ferric oxide (Fe_2O_3)....	2.63	4.03	2.25	1.39	0.54
Ferrous oxide (FeO)....	3.52	2.46	3.66	0.84	n.d.
Lime (CaO).....	4.90	3.12	1.54	1.05	42.61
Magnesia (MgO).....	4.36	2.45	2.60	0.52	7.90
Soda (Na_2O).....	3.55	1.31	1.19	0.76	0.05
Potash (K_2O).....	2.80	3.25	3.69	1.16	0.33
Combined water.....	1.52	3.68	3.51	1.47	0.56
Moisture.....	.....	1.34	0.62	0.27	0.21

* Including small amounts of titanic oxide (TiO_2).

In the case of such sedimentary rocks as the sandstones and shales, the entire process is a purely mechanical matter, the materials being carried in suspension by moving water, and being deposited because of decrease in the velocity of the water which has transported them.

The limestones, however, present a more complicated case, for the lime and magnesium carbonates of which they are formed are usually carried in solution by water, and are deposited by chemical or organic agencies. These differences in origin and deposition will be taken up in more detail in later chapters, where the various kinds of sedimentary rocks are separately discussed.

Genetic Relationship of the Rock Classes.—It may aid the reader to comprehend more fully the closely interwoven relationships of the various classes of rocks if the discussion be carried a stage further, and some consideration given to their relationship so far as origin is concerned. So far as known to the writer, the matter which is here presented has never, even in purely geologic treatises, been set forth in a closely analytical form, though of course the ideas which underlie this analysis are generally accepted.

The accompanying diagrammatic table (Table 2) has been prepared to serve as a convenient semigraphic summary of the statements in the following paragraphs, and should consequently be studied in connection with those paragraphs. In order to facilitate this cross reference, the notation used in the table has also been employed to designate the corresponding steps in the more detailed discussion below.

I. For our present purpose it will be sufficiently exact to consider that, in the earliest stage to which we need refer, the earth's crust was already solidified by cooling, and that it was composed entirely of igneous rocks. These rocks intergraded closely in composition, but for convenience here may be divided into an acid group (I *a*) and a basic group (I *b*). The acid group would include those rocks higher in silica than the average noted on page 8, while the basic rocks would include those lower in silica than the average. The dividing line between the two groups is therefore fixed naturally at about 59 per cent silica.

II. The igneous rocks forming the exposed portion of the crust were almost immediately attacked by both mechanical and chemical agencies of destruction. The two sets of agents undoubtedly commenced their destructive action almost simultaneously, but it will be logically exact and certainly conducive to clearness in the present discussion if we at first consider only the effects of purely mechanical attack on the exposed crustal rocks.

The effect of heat and cold, rain and running water, on a series of rocks is to ultimately effect the mechanical disintegration of a portion of the exposed outcrop. The material thus broken down mechanically is carried off by running water and finally deposited. Since it is assumed that this entire process has not been assisted by chemical action, and that the material deposited has not been subjected to mechanical concentration or sorting, the ultimate result would be the formation of a bed of sandy clay. In composition this clay would not differ greatly from the average composition of the igneous rock from which its materials were derived. The clays thus formed would be either typically siliceous clays (II *a*) or basic clays (II *b*) according to the character of the particular igneous rocks from which they were derived.

III. As a matter of fact, however, both leaching and sorting must have taken place at an early period in the history of the

sedimentary rocks. The principal sorting effect would be the mechanical separation of the particles of quartz from the other residual material, owing to the greater resistance of quartz to both mechanical and chemical attack. The sorting out of this quartz and its separate deposition would give rise to the formation of beds of sand and gravel (III *c*). The principal effect of chemical attack would be the removal of lime in solution. The lime thus carried off would be redeposited, either through direct chemical action or by the agency of living organisms, to form marl deposits, shell beds, etc. (III *d*).

TABLE 2.—STAGES IN THE ORIGIN OF ROCK CLASSES.

Stages of origin.	Siliceous.	Silico-aluminous.		Calcareous.
I. Original constituents of the earth's crust.		I <i>a</i> . Acid rocks	I <i>b</i> . Basic rocks	
II. Derived from I by mechanical erosion and sedimentation without sorting.		II <i>a</i> . Acid clays	II <i>b</i> . Basic clays	
III. Derived from I or II, with the aid of mechanical sorting and chemical leaching.	III <i>c</i> . Beds of sand and gravel.	III <i>a</i> . Acid clays	III <i>b</i> . Basic clays	III <i>d</i> . Shell beds, marl deposits, etc.
IV. Derived from III by normal consolidation.	IV <i>c</i> . Sandstones	IV <i>a</i> . Acid shales	IV <i>b</i> . Basic shales	IV <i>d</i> . Limestones
V. Derived from IV by metamorphism.	V <i>c</i> . Quartzites	V <i>a</i> . Acid slates	V <i>b</i> . Basic slates	V <i>d</i> . Marbles

The mechanical removal of silica and the chemical removal of lime would leave the balance of the residual material still in the class of clays, as III *a*, and III *b*, but somewhat poorer in silica, lime and other soluble constituents than if such sorting and leaching had not taken place.

IV. The deposits thus far considered are still to be regarded as relatively unconsolidated beds of material. As these beds were covered by later rocks, pressure, heat and renewed chemical action were gradually brought into play. The result was that

the beds of sand and gravel (III *c*) became ultimately sandstones (IV *c*); the clays (III *a* and III *b*) became shales (IV *a* and IV *b*); while the calcareous deposits (III *d*) became limestone (IV *d*). No serious chemical change resulted from this consolidation, so that the rocks of the subgroups of IV are closely akin chemically to the unconsolidated deposits of III from which they were respectively derived.

V. In most cases the process of consolidation stopped at the stage which has just been discussed, but locally the consolidating agencies persisted in their work to a point where the physical changes which they caused warrant us in giving another name to the product. Thus the sandstones (IV *c*), if consolidated very intensely, might locally become quartzites (V *c*); the shales (IV *a* and IV *b*) in places became slates (V *a* and V *b*); and the limestones (IV *d*) in metamorphic regions became marbles (V *d*). In these further consolidations the chemical changes which take place are very slight as compared with the purely physical alterations.

THE STRUCTURES OF ROCKS.

Under this heading will be discussed such structural features as are common to all classes of rocks. Structures peculiar to the igneous rocks will be considered in Chapter II, while those peculiar to the sedimentary rocks will be discussed in Chapter VI.

As thus limited, the structural conditions to be considered in the present section include the inclination of beds (dip, strike, etc.); rock folding; faults; jointing and cleavage.

Inclination of Beds; Dip and Strike. — The beds of sedimentary rocks, having been formed for the most part by deposition on the gently sloping bottoms of bodies of water, would naturally have a horizontal or nearly horizontal attitude at the time of their formation. But during the numerous elevations and depressions of the land which have occurred since their deposition, this original horizontality of bedding was in many cases destroyed, so that now we may find sedimentary rocks whose beds are inclined at all angles to the horizontal. This is particularly true in the Appalachian, Lake Superior, Rocky Mountain and Pacific Coast regions, where horizontal strata are the exception rather than the rule. In the central United States, however, most of the rocks still lie almost or quite horizontal, an inclina-

tion of over five degrees being distinctly uncommon in the States of the Mississippi basin.

In describing the attitude of a bed inclined to the horizon, it is necessary to do so in terms of *dip* and *strike*; which requires that these two terms be defined. The *strike* of an inclined bed may be roughly defined as the direction or trend of the bed. To

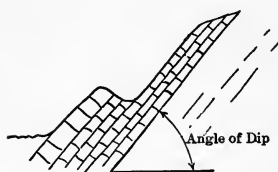


Fig. 2. — Angle of dip.

be more precise, it is the compass bearing of a straight line drawn horizontally on one of the faces of the bed. The *dip* of the bed is the angle made with the horizontal by a line drawn on the surface of the bed, at right angles to the strike (Fig. 2). Since the two factors are thus related, it is unnecessary to

give the exact compass bearing of the dip (for that will always be at right angles to the strike) but merely the quadrant. In description it is therefore sufficient to say, for example, that a rock has a strike of N. 30° E., dip 35° S. E. — which can readily be seen to imply that the dip of 35 degrees is in the direction S. 60° E.

Though, from a very strict standpoint, the terms *dip* and *strike* would be applicable only in describing the bedding planes of sedimentary rocks, there is no real reason for not using them in describing the attitude of the laminated igneous rocks (gneisses, schists, etc.), and they are commonly so applied.

Rock Folds. — The terms dip and strike having been defined, it is possible to glance at certain broader features of rock structure of which dip and strike are merely local manifestations. These broader features are connected with the subject of rock folding.

In the course of earth movements, folds and flexures of various types are developed in beds of rock which may previously have been horizontal. If the movement simply elevates or depresses one side of an area, so that as a result the rocks everywhere dip in the same direction, the resulting attitude of the rocks is called a *monocline*. If, however, compressive or tensile stresses accompany the uplift or depression, a complete fold of some sort will be formed.

When a complete fold is presented for observation, it may be either a *syncline* or trough, in which the strata on both sides dip

toward the axis of the fold; or an *anticline* or arch, in which the strata on both sides dip away from the axis of the fold. Fig. 3

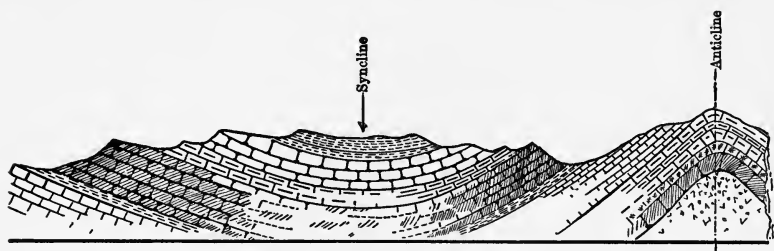


Fig. 3. — Syncline and anticline.

shows both of these structures, a very sharp anticline being shown at the extreme right of the figure, while a rather flat syncline occupies the remainder of the sketch.

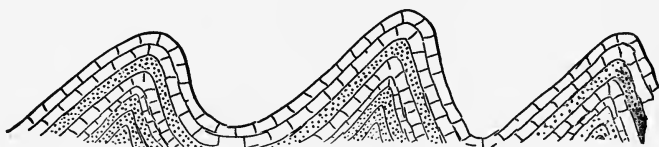


Fig. 4. — Folds with inclined axes.

In the simple forms of these folds shown in Fig. 3, the axes of the folds are vertical in each case, and there is no particular compression of the limbs of the folds. In more complex cases we find folds with inclined axes, as is shown by those represented in Fig. 4; or with extremely compressed limbs as shown in Fig. 5.

Faults in Strata.— When, in the course of earth movements, the strata subjected to stress are too rigid to yield by simple folding, or when the stress is applied

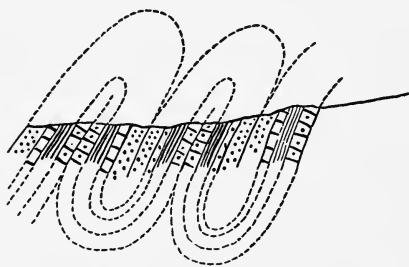


Fig. 5. — Compressed folds.

too rapidly, they will yield by fracture. Such fractures, which may occur at any point in the stressed area, result in the formation of a *fault*, which may be considered simply as a break in

the continuity of the strata, accompanied by elevation or depression of the beds on one side of the fault plane.

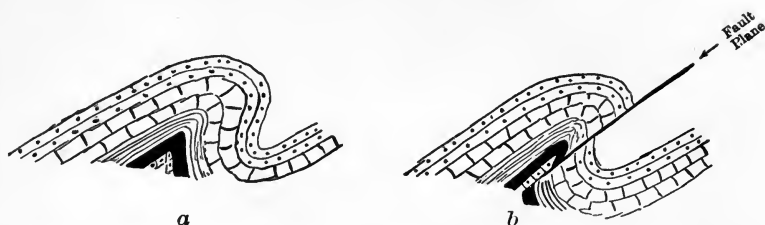


Fig. 6. — Origin of thrust faults: *a*, overturned fold in rocks, passing by fracture into *b*, thrust fault.

On a large or small scale, faulting is a very common phenomenon, particularly in regions of intense folding. It is a matter of peculiar economic importance to the mining engineer, since the existence of faults in a district complicates the underground structure, and renders it difficult to follow out a mineral deposit affected by faulting. For our present purposes, however, the subject of faulting requires little consideration, for no engineer would consider opening a structural stone quarry in a badly faulted area. On the other hand, the existence of numerous faults might be a distinct advantage in operating a quarry for crushed stone.

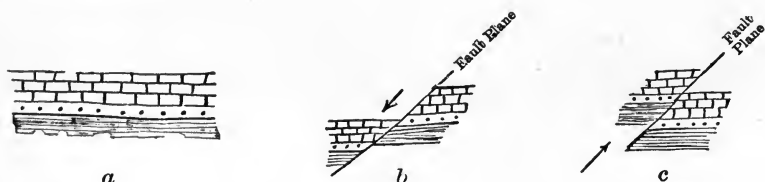


Fig. 7. — Faults in strata: *a*, original attitude of strata; *b*, position after normal faulting; *c*, position after reverse faulting.

Joints. — A sedimentary rock, as originally deposited, would probably show more or less distinct bedding planes (see page 93), and would have a tendency to break or split parallel to these planes. But it would not have any planes of easy fracture transverse to the bedding planes, for in this direction the stone would be entirely homogeneous and massive. Igneous rocks, cooled entirely without interference, would be even more homo-

geneous; and would not show planes of easy fracture in any direction.

As a matter of fact, however, both sedimentary and igneous rocks do commonly show certain planes (entirely distinct from the bedding planes in the case of the sedimentary rocks), along which they break or cut with greater ease than in any other direction. When these planes are so marked as to show on the surfaces of the rock, dividing it into more or less rectangular



Fig. 8. — Joint planes in sandstone. (Photo by E. M. Kindle.)

masses, they are described as *joints* (Fig. 8). When the fracture planes do not show on the surface, but merely exist as planes of weakness within the rock itself, we have the *rift* and *grain* which are discussed in a later section (page 39) in describing the structure of granites.

Recurring to the subject of jointing, the examination of a quarry will show almost invariably that the rock breaks out in rectangular or prismatic blocks; and that the surfaces which bound these blocks are parallel to one or more systems of joints.

As to origin, joint planes may be due to cooling stresses (in

the case of igneous rocks); to drying, in the case of sediments; or to earth movements after deposition, in the case of either igneous or sedimentary rocks.

SUGGESTIONS FOR GEOLOGIC READING.

The subjects discussed in this chapter may perhaps be completed most profitably by a brief reference to a few books dealing with various phases of engineering geology in more detail than has been possible here. The writer has no intention of outlining a course of geologic study, but will simply note the lines along which further reading may be useful to the engineer desirous of securing a working acquaintance with both geologic theory and practice, so far as they affect his own work.

1. As to general geology, one of the more elementary textbooks, such as those of Tarr or Brigham, will in most cases be more satisfactory than a larger treatise. The best manual, of course, is the *Geology* of Chamberlin and Salisbury, but this is too bulky, too detailed and too expensive to be generally serviceable.

2. The next stage is some degree of acquaintance with the field practice of geology, including knowledge of the facts which should be observed and of the methods adopted in noting, recording, and interpreting these facts. In this field Geikie's *Structural and Field Geology* is still unsurpassed as a general guide for field work; while Grenville-Cole's *Aids in Practical Geology* contains valuable data relative to the rocks, minerals, and fossils which may require determination. Both of these books are English, and therefore much of their illustrative matter will be unfamiliar to the American reader; but in spite of this drawback Geikie's book at least can hardly be dispensed with.

3. Further study of the structures and classification of rocks, and of the processes involved in their origin and decay, will fortunately be aided by two books which are at once readable and authoritative. Reference is here made to Kemp's *Handbook of Rocks* and to Merrill's *Rocks, Rock Weathering, and Soils*. The two do not cover exactly the same ground, but supplement each other admirably. Of the two, Kemp's book should be taken up first, and is probably of more general service; but Merrill's volume has a more direct bearing on the problems involved in the weathering and decay of building stone.

CHAPTER II.

IGNEOUS ROCKS IN GENERAL.

IN the previous chapter the origin and characters of the igneous rocks have been briefly noted, but only as connected with the relationships of the various rock classes, and not in the detail required by their industrial importance. In the present chapter the more important characteristics common to all igneous rocks will be discussed in such detail as seems advisable, while the special characteristics of the granites and traps will be taken up in the later chapters in which these two commercial subgroups of the igneous rocks are described.

Origin of Igneous Rocks. — According to the more commonly accepted theories, the entire earth was at one time a molten mass; and at least part of its interior is still either fluid or on the verge* of fluidity. The igneous rocks, as now found at the surface, comprise the materials which have solidified and crystallized by cooling from this state of fusion. The solid crust first formed on the cooling earth was of course composed entirely of igneous rocks, and it is possible (though highly improbable) that portions of this original crust are still exposed at various points on the present surface of the earth. Most of the igneous rocks, however, have solidified at later periods of the earth's history, having been forced upward into or through the overlying rocks, and having passed upward until they reached a point at which decreased pressure and lowered temperature have allowed the molten material to cease its movement, to cool and to crystallize.

Modes of Occurrence of Igneous Rocks. — Both scientific and economic interest attach to a study of the modes in which igneous

* In explanation of this, it is clear that the pressure of overlying rocks may be sufficient to keep the interior in a solid condition, even though the temperature in the depths may be above that which would be required to melt these rocks if they were at the surface. Under these conditions, any release of pressure will, of course, immediately permit the highly heated rock material to become fluid.

rocks have reached their present condition at the earth's surface, so that attention can properly be directed to a brief discussion of the principal modes of occurrence.

For our present purposes, the principal types which require consideration are the following:



Fig. 9. — Granite boss rising above limestone plain. (Photo by E. C. Eckel.)

1. *Stratiform Masses*. — It would of course be incorrect to apply the term "stratified" to igneous masses, for owing to their origin the term would be obviously a misnomer. But on all the continents it is found that the Archæan rocks are composed largely of igneous materials. These include both basic and acid rocks, and vary in structure from entirely massive to thoroughly gneissoid types. It is impossible to prove at present that these Archæan igneous rocks were ever intruded into other formations. In most cases all that can be said about their mode of occurrence is that they now exist, covering immense areas on the earth's surface, and serving as a basement or floor on which the earliest known fossiliferous rocks were deposited. Because of the facts that they can be separated into different formations,

that they have no definite relation to sedimentary rocks of the same date, and that they are generally thoroughly laminated and folded, it is convenient to use the term *stratiform masses* in describing them.

2. *Batholiths*. Along the axes of many mountain chains are found vast masses of granitic and other igneous rocks, evidently intruded into existing sedimentary deposits, but having cooled at a considerable depth below the surface of the earth. These cores or *batholiths* are now exposed at the surface simply because the sedimentary rocks which once overlay them have been removed by erosion. Smaller masses of the same general type, weathered out so as to project above the general surface level, are referred to as *bosses* or *stocks*. One of these is illustrated in Fig. 9.

3. *Laccoliths*. The two types of rock mass which has been discussed above agree in that their cooling took place so far below the surface that the nearness of the latter had no effect on the shape of the mass or on the texture of the rock. In the modes of occurrence which remain to be discussed this was not the case.

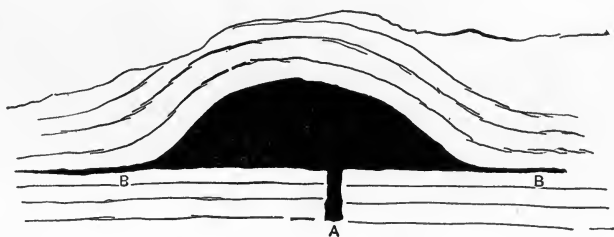


Fig. 10. — Laccolith, with supply neck (A) and sheets (B).

A mass of heated igneous rock, rising upward through approximately horizontal existing strata from a molten reservoir might conceivably reach a point at which it would be easier to force the overlying strata up into a dome or arch rather than to break away through them. The igneous rock, cooling in the arched cavity thus formed, would take the form of a *laccolith*. In Fig. 10 a typical laccolith is shown in cross section, together with some of the phenomena which usually accompany it.

4. *Volcanic products*. If the igneous rock penetrated to the surface, and issued at some particular point of weakness, a volcano

would be formed. As shown in Fig. 11, this would usually involve the creation of the *volcanic neck* or passage through which the igneous rock reached the surface, the subsequent building of a *cone* of ashes or lava, and in some cases the flow of a more or less extensive *lava sheet* over the adjoining surface.

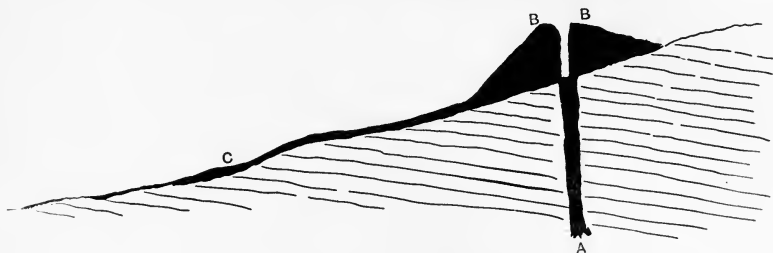


Fig. 11. — Volcanic neck (A), cone (B) and surface flow (C).

5. *Dykes, Sheets and Sills.* Certain minor types of occurrence, which may be connected with either volcanic or intrusive action, remain to be noted. Igneous rock might reach upward toward the surface through approximately vertical fissures. The rock which cooled in these fissures would form a *dyke*, as illustrated in Figs. 12 and 13. If at any point a supply of igneous rock penetrated laterally along the bedding planes of a sedimentary formation, it would form on cooling an *intrusive sheet* or *sill*. Examples of these are also shown in Figs. 11 and 12.

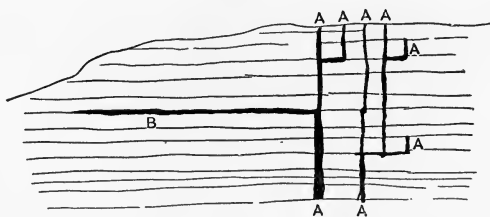


Fig. 12. — Dykes (A, A) and sheet or sill (B).

Texture of Igneous Rocks. — When molten masses cooled in large bodies, or at considerable depths below the surface, the solidification was in consequence so slow as to permit the formation of large crystals of the different constituent minerals. Our ordinary granites are good examples of such slowly cooled prod-

ucts. But when the local supply of molten material was small, or when solidification took place at or near the surface, the cooling was so rapid that the resulting rocks are made up of very small mineral crystals, often enveloped in a glassy matrix; while

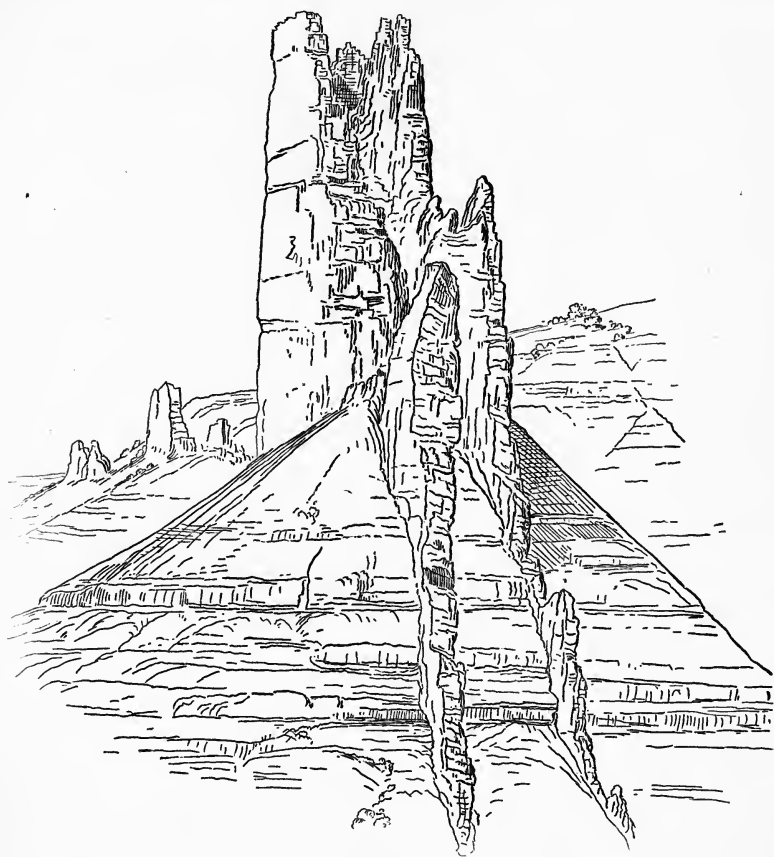


Fig. 13. — Dykes made prominent by weathering. (Hayden Survey.)

a still more rapid cooling might result in a rock having an entirely glassy structure, absolutely free from crystals. If, as happened in places, the igneous material was introduced into the air or into water while still molten (as in volcanic action), the result was the formation of porous products — volcanic ash, pumice, etc.

Perhaps the conditions above outlined may be more clearly realized if they are compared with a parallel series of perfectly

familiar phenomena which occur every day in the handling of slag at blast furnaces. If furnace slag is cooled with very great slowness, it will develop crystals of various silicate minerals. On the other hand, the slag as it usually cools on a slag bank has an entirely glassy texture. Finally, if the molten slag is led into water, or if a current of steam, air or water is injected into the stream of molten slag, the slag will cool or granulate so suddenly as to assume a porous texture, exactly like a volcanic ash.

Structure in Igneous Rocks.— Since all igneous rocks are formed by direct cooling from a state of fusion, it is obvious that none of them can show any true bedding, for that is a characteristic of materials deposited by or in water. The differences in structure can not be due to the sorting influence of water, but must be entirely due to the varying conditions under which they cooled, or to the effects of later earth movements on the cooled mass. Considering igneous rocks in general, two different types of structure may exist.

1. In an igneous rock which has solidified quietly from a fused state, and which has not been later subjected to severe external stresses, the constituent mineral crystals are confusedly arranged, showing no trace of parallel banding or lamination. Such rocks are termed *massive* igneous rocks. Most of the granites used for structural purposes, and practically all of the trap rock used commercially, fall in this class.

2. If, however, rocks of this same origin and composition had been subjected, either during or after their cooling, to external pressure, a laminated structure might have been developed. When this has occurred under favorable conditions the constituent minerals may be arranged in more or less definite alternating bands; while when the lamination is less completely developed the mineral crystals will merely be arranged with their longer axes in the same direction. In either case the rock is termed a *gneiss*. Some of the rocks which commercially are classified as granite, and are used in structural work, are in reality sufficiently well laminated to be properly called *gneisses*.

Chemical Composition of Igneous Rocks.— The igneous rocks consist largely of silica — from 35 to 80 per cent — with lesser amounts of alumina. According to their class they may also contain more or less iron oxides, lime, magnesia, potash and

soda. These are the principal constituents which are present, in varying amounts, in practically all of the igneous rocks. Many other constituents are present in small percentages, but are of little general importance and do not require further notice here.

Such wide variation exists in the composition of the different types of igneous rocks, that few general statements can be made which will apply to the group as a whole. Analyses of these various rock types will be given later, in the chapters dealing with them separately, but in the present place attention may be called to the data presented in Table 3. This table includes averages, of two long series of analyses of igneous rocks; and the two results may fairly be regarded as closely representative of the composition of the *average* igneous rock.

TABLE 3. — AVERAGE ANALYSES OF IGNEOUS ROCKS.

Constituent.	A.	B.
	Per cent.	Per cent.
Silica (SiO_2).....	59.71	58.75
Alumina (Al_2O_3) *.....	16.01	15.76
Ferric oxide (Fe_2O_3).....	2.63	5.34
Ferrous oxide (FeO).....	3.52	2.40
Lime (CaO).....	4.90	4.98
Magnesia (MgO).....	4.36	4.09
Potash (K_2O).....	2.80	2.74
Soda (Na_2O).....	3.55	3.25
Water.....	1.52	2.23

* Including small amounts of titanic oxide (TiO_2).

A. Average by F. W. Clarke, of 830 analyses of American igneous rocks.

B. Average by Harker, of 397 analyses of British igneous rocks.

The terms *acid* and *basic*, as often applied to igneous rocks, require some note. Acid rocks are those containing high percentages of silica and low percentages of lime, magnesia, alkalies and iron oxide. Basic rocks, on the other hand, are high in iron, magnesia, etc., and comparatively low in silica. The two classes intergrade with each other and the dividing point between the acid and the basic rocks is fixed by different writers at different percentages of silica. Certainly, acid rocks must in average composition contain more silica than basic rocks: but the dividing line is purely arbitrary. It is both convenient and logical to use the average analyses presented in the preceding table as a basis for fixing this dividing point, and to consider that any igneous

rock higher in silica than the average is an acid rock, while any rock lower in silica than the average is a basic rock. In the present volume, therefore, when it is necessary to use these terms precisely, the dividing point between the two classes will be considered to be 59 per cent of silica. The differences in chemical composition cause differences in physical characters. Certain acid rocks may, in average density, range higher than exceptional basic rocks: but in general the acid rocks are distinctively lighter than the basic.

Mineral Constituents of Igneous Rocks. — The igneous rocks which have crystallized out completely are composed of an intimate mechanical mixture of various silicate minerals. Those in which the cooling has been too rapid to permit of thorough crystallization consist more or less entirely of a formless silicate glass. Since this latter class can not be identified by mineral composition, the paragraphs which immediately follow must be understood to relate only to such igneous rocks as are entirely or largely crystallized.

The total number of mineral species which may occur in igneous rocks is very large; but only a few of these species are of real importance in the present connection. Fortunately the lighter colored coarse-grained rocks which furnish most of our structural stone usually contain few mineral species — commonly only three or four are present in quantity — and these are readily recognizable. The finer grained or partially glassy igneous rocks, on the other hand, can not be properly classified without the aid of chemical analysis or microscopic investigations; but the rocks of this type are not of high industrial importance for structural purposes.

The minerals which make up the bulk of the igneous rocks used for structural purposes represent five species or groups of species. These are in order of importance:

- (1) Quartz.
- (2) The feldspars.
- (3) The micas.
- (4) The amphibole-pyroxene group.
- (5) Olivine.

Several minor minerals are of sufficient importance to require brief mention, while certain minerals which occur as secondary

or alteration products may also be noted. These will be taken up after describing the five principal groups listed above.

(1) *Quartz*, which is composed entirely of silica (SiO_2), occurs in the granites and many other igneous rocks. It is also, it may be noted, the principal constituent of the sandstones. In the granites, quartz commonly occurs as a transparent or translucent mineral, varying in appearance from clear, colorless and glasslike to light grayish or light bluish. It shows no regular, smooth surfaces or fracture planes; but breaks with a rough, irregular, glassy fracture. It can not be scratched with a knife, being hard enough to scratch window glass. The specific gravity of pure quartz is close to 2.65.

(2) The *feldspars* are a group, including a long series of complex silicate minerals. The most prominent members of this group are *orthoclase*, *albite*, *labradorite*, *anorthite*, *oligoclase* and *microcline*. The distinctions between the various feldspars can rarely be made out except by chemical analysis; but the group, taken as a whole, can be described quite satisfactorily.

The feldspars occurring in most building stones are commonly white to gray or reddish in color — more rarely dark blue or gray; on breaking, they fracture with a very regular smooth polished cleavage surface in at least one direction, and frequently they show two such regular cleavages.

Chemically, the feldspars fall into two quite distinct subgroups; the *orthoclase* or potash feldspars and the *plagioclase* or soda-lime feldspars. The former group contains only two mineral species — *orthoclase* and *microcline* — which differ only in optical characters. The plagioclase group is more complex, containing a long series of feldspars ranging in composition from *albite* (a soda feldspar) at the one extreme to *anorthite* (a lime feldspar) at the other. The intermediate stages in this series have been given distinct names, but may probably be regarded simply as mixtures of albite and anorthite molecules in various proportions.

In the following table the composition and specific gravity of the various feldspars are recorded. Orthoclase is placed first, after which the various plagioclase feldspars follow in the order of their decrease in silica content.

The orthoclase and plagioclase feldspars differ little in appearance, so that it is difficult to distinguish them except under the microscope or by analysis. This is unfortunate, for the distinc-

tion between the two subgroups is often important, since they differ in geologic associations as well as in composition. Orthoclase is a common constituent of the more acid igneous rocks, such as the granites and syenites; while the common feldspar of basic rocks such as trap, gabbro and basalt is invariably a plagioclase feldspar.

TABLE 4.—COMPOSITION AND SPECIFIC GRAVITY OF THE FELDSPARS.

Name.	Specific gravity.	Formula.	Silica.	Alumina.	Potash.	Soda.	Lime.
Orthoclase...	2.57	$K_2O, Al_2O_3, 6 SiO_2$	64.60	18.50	16.90	....	....
Albite.....	2.62	$Na_2O, Al_2O_3, 6 SiO_2$	68.62	19.56	....	11.82	....
Oligoclase...	2.64	.....	63.70	23.95	1.20	8.11	2.05
Andesine.....	2.65	.....				
Labradorite .	2.69	.....	52.90	30.30	....	4.50	12.30
Bytownite....	2.71	.....				
Anorthite....	2.75	$2 CaO, Al_2 O_3, 4 SiO_2$	43.08	36.82	....	....	20.10

One point which often aids in the separation of the two groups may be noted. The cleavage faces of orthoclase are perfectly smooth, while close examination of the cleavage faces of a plagioclase feldspar will often show that they are crossed by a series of close-set parallel lines. Color and association also aid somewhat in the distinction. Orthoclase is usually white, pinkish, red or very light grayish in color; and is frequently associated with quartz. A white plagioclase feldspar, in a rock which also contains considerable quartz and orthoclase, is probably albite. On the other hand, a bluish or dark gray plagioclase feldspar, in a rock containing little or no quartz or orthoclase, is labradorite or another of the more basic plagioclases.

(3) The *micas* occur in glistening scales or flakes, usually white, yellowish dark brown, or black in color. They include two common species — muscovite and biotite — and several species of less importance. Mica, the familiar “isinglass” of stove doors, is readily scratched by a knife, and even more readily split into thin leaves or flakes along its cleavage planes. The light-colored micas can not be mistaken for any other common mineral in igneous rocks. The dark micas, however, might be confused with hornblende or augite, since both show the same dark-colored smooth glistening surfaces; but the splitting properties of the mica are not shared by hornblende or augite.

Though a number of species of mica are recognized, only two are sufficiently common as rock-forming minerals to require consideration here. The two common species are, as above noted, muscovite and biotite. Of these, muscovite is a light-colored mica, occurring frequently in granites, schists and the more acid gneisses; but very rarely in the gabbros, basalts and similar basic rocks. Biotite, on the other hand, occurs very commonly in certain basic rocks; and somewhat less frequently than muscovite in the more acid types.

Fairly representative analyses of specimens of these micas are given below:

TABLE 5.—ANALYSES OF MICAS.

	Muscovite.	Biotite.
Silica.....	46.3	40.0
Alumina.....	36.8	17.28
Ferric oxide.....	4.5	0.72
Ferrous oxide.....	....	4.88
Magnesia.....	....	23.91
Potash.....	9.2	8.57

Comparison of these analyses will show that muscovite is relatively high in alumina, while biotite contains large percentages of magnesia and ferrous oxide. This results in characteristic differences in weathering, for while muscovite is little affected by atmospheric action, the oxidation of the ferrous iron in the biotite makes it assume a more or less rusty appearance on long exposure. Muscovite is slightly lower in specific gravity—2.6 to 3.0, as compared with the 2.8 to 3.2 of biotite.

(4) The *amphibole-pyroxene group* includes a large number of species, two of which are of common occurrence in igneous rocks. These are hornblende (amphibole) and augite (pyroxene), which are not readily distinguished from each other in the hand specimen. Both are commonly green to almost black in color, and usually break with one smooth fracture surface; but are distinguishable from the dark micas, which they often resemble in appearance, in not being readily split into thin leaves or plates.

Though non-aluminous amphiboles and pyroxenes occur, the hornblende and augite which are the common rock-forming

varieties are essentially silicates of alumina, lime, magnesia and iron. The following analysis is fairly representative.

Silica.....	48.8
Alumina.....	7.5
Ferrous oxide.....	18.2
Lime.....	10.2
Magnesia.....	13.6

Hornblende occurs more frequently in diorites and granites, while augite is characteristic of the more basic rocks. Slight differences of specific gravity are to be noted, that of hornblende ranging commonly from 3.15 to 3.33, while that of augite varies from 3.3 to 3.55.

(5) *Olivine* or *peridot* is a silicate of iron and magnesia occurring as an essential constituent of the ultra-basic igneous rocks; and as a common constituent of all the basic rocks. It usually occurs in small glassy grains, varying in color from yellowish green to olive green. The grains are brittle, and usually will show one smooth cleavage or fracture surface.

One of the more important relations of olivine to the stone industry arises from the fact that some of the serpentines discussed in Chapter V have originated through the alteration of rocks rich in olivine.

Certain other minerals are apt to be developed as *secondary* products, in case the rock has undergone alteration or more or less complete decomposition. The more important of these secondary minerals are calcite, magnesite, kaolinite, chlorite and serpentine. It is to be noted that, of this group, kaolinite is the only species likely to result from the alteration of the *acid* igneous rocks; the other four secondary minerals being more commonly associated with the decomposition of *basic* rocks.

The Classification of Igneous Rocks. — The classification of the massive igneous rocks, as at present practiced by professional petrographers, has attained a degree of precision and refinement which renders it entirely useless to the engineer or quarryman. The systematic classification now adopted by most American petrographers is based upon chemical analyses of a grade unattainable in ordinary laboratory practice, interpreted and supplemented by means of the microscope. In the hands of a specialist such chemical and optical data can be combined to

give results of great exactness, but by others than specialists they can not be safely applied, and the classification * based upon them is of no economic importance.

For our present purposes, the following grouping will be found sufficiently accurate and precise.

A. Rocks which are entirely crystallized, so that each of the constituent minerals is recognizable.

1. **Granites:** composed essentially of quartz and feldspar; with usually lesser amounts of mica, or hornblende, or both. The feldspar is occasionally all orthoclase; but commonly some plagioclase is also present. The mica may be either muscovite, or biotite, or both.
2. **Syenites:** composed essentially of feldspar, with subordinate amounts of mica or hornblende. Quartz is entirely or practically lacking. The feldspar is usually a mixture of orthoclase and plagioclase.
3. **Diorites:** composed essentially of hornblende and feldspar, the former being in excess. Mica, usually biotite, may be present in considerable quantity. Quartz is rare or absent. The feldspar is commonly a plagioclase, though orthoclase may also be present in subordinate amounts.
4. **Gabbros:** composed essentially of pyroxene and feldspar, the former being in excess. Olivine may be present, as well as biotite. The feldspar is usually one of the more basic plagioclases.
5. **Hornblendites:** composed essentially of hornblende, feldspar being absent. Pyroxene and olivine may be present in subordinate amounts.
6. **Pyroxenites:** composed essentially of pyroxene, feldspar being absent. Hornblende and olivine may be present in subordinate amounts.

* The reader desirous of further enlightenment regarding this classification may, at his own risk, read the papers noted below:

Cross, W., and others. A quantitative chemico-mineralogical classification and nomenclature of igneous rocks. *Journal of Geology*, vol. X., pp. 555-690, 1902.

Washington, H. S. Chemical analyses of igneous rocks published from 1884 to 1900, with a critical discussion of the character and use of analyses. Professional Paper, No. 14, U. S. Geol. Survey, 495 pp., 1903.

7. **Peridotites:** composed essentially of olivine (peridot), feldspar being absent. Pyroxene and hornblende may be present in subordinate amounts.

B. Rocks in which the bulk of the rock forms a dense fine-grained, unrecognizable groundmass, through which a few relatively large mineral crystals are scattered. These rocks are the porphyries. They may be further subdivided into quartz-porphyry, feldspar-porphyry, etc., according to the particular mineral which makes up the visible crystals.

C. Rocks in which no mineral constituents are recognizable, the rock being a dense, fine-grained mass of microscopic crystals often with minor amounts of glassy matter. Subdivided on the basis of color and composition into:—

1. Felsites; light colored, acid rocks.
2. Basalts; dark colored, basic rocks.

D. Rocks which show no trace of crystallization, being glassy throughout. The volcanic glasses, which require no further consideration here.

Since any of the above types of igneous rock may have been subjected, during or after cooling, to pressure sufficient to cause banding, we may find types of *gneisses* corresponding in composition to any of the groups of massive rocks. A rock consisting of quartz, feldspar and mica, arrayed in quite definite layers, would be a *granite-gneiss*; a similarly laminated rock consisting chiefly of pyroxene and feldspar would be a *gabbro-gneiss*; and so on.

Commercial Classification of Igneous Rocks. — The scientific classification of the various igneous rocks is a matter of great complexity, as has been noted above. Fortunately or unfortunately, engineers and quarrymen have adopted a very simple working classification, recognizing only the following groups:

(1) *Granites:* including the lighter colored, less dense, coarser grained igneous rocks, usually containing much quartz.

(2) *Traps:* including the dark colored, dense, heavy igneous rocks, composed mostly of pyroxene, basic feldspars, etc., with little or no quartz.

To these should be added a third class, usually derived from basic igneous rocks by weathering and other alteration processes.

(3) *Serpentines*: including a series of (usually green) soft rocks, composed mostly of hydrated magnesium silicates.

Pumice, lava, and other igneous products which have cooled rapidly at the earth's surface require no special comment here, being usually unfit for structural purposes and therefore of little importance to the engineer. It may be noted, however, that the natural puzzolan materials often used as cements (pozzuolana, trass, santorin, etc.) are all volcanic ashes.

The distinction thus made by the trade between "granite" and "trap," though not in complete accord with scientific grouping, has certain underlying principles of commercial usefulness. The dark-colored basic rocks called "traps" agree in being tough and difficult to quarry and dress, of dark and somber colors, and rather susceptible to weathering; while the light-colored acid "granites" are more readily excavated and cut, usually of light and pleasing colors, and more resistant to atmospheric agencies. The serpentines differ from both of these classes in their fairly uniform greenish colors and in their softness.

The relation between the scientific and the commercial classifications of rocks is about as follows (compare page 29, et. seq.). Under the head of *granite* the quarryman includes all the true granites and syenites, and the coarser-grained varieties of diorite and gabbro, though the last of these is rarely used for structural purposes. The trade name *trap*, on the other hand, includes the basalts, the peridotites, pyroxenites and hornblendites, and the finer-grained varieties of diorite and gabbro, though most commercial trap is either basalt or a fine-grained gabbro. The other rocks listed in the scientific grouping — felsite, porphyry and the volcanic glasses — are rarely used in structural work. The *serpentines*, though usually derived from igneous rocks, find no place in the scientific classification above presented because they are not original but secondary products.

CHAPTER III.

GRANITES AND OTHER ACID ROCKS.

Scope of the Term Granite. — The term granite, as used in the stone industry, and as it will be employed usually in the present chapter, includes practically all of the igneous rocks *except* the traps and serpentines. This is a negative and apparently very loose definition, but as a matter of fact the term can be defined much more closely without seriously interfering with its trade application.

|| By far the majority of the "granites" known to the stone trade are light-colored, coarse-grained stones, composed largely of quartz and feldspar, with usually some mica, occasionally hornblende, and rarely augite. || The commercial granite, therefore, is almost always a rock of the type which the geologist would also include in his more restricted use of the term granite. Occasionally, however, we find syenites and the coarser-grained gabbros and diorites handled under the trade name of "granite," but though these exceptions require note, it must be borne in mind that they *are* exceptions. In 99 cases out of 100, the granite of the stone trade is also the granite of the geologist.

In certain parts of the country, however, the term granite is misapplied to kinds of rock which have no possible claim to it. This is often the case in districts where igneous rocks are scarce or entirely wanting; and in such districts sandstone and even limestone may be found, in certain local markets, under the local trade name "*granite*." Such a misapplication of the term has nothing to excuse it, from any point of view, and the most reasonable way to treat it is as an attempt to cheat the purchaser.

The trade distinctions between the different kinds of granites are based largely upon differences in color, coarseness of grain and mineral constituents; for most of the technical properties and commercial values of granites depend on these three factors.

ORIGIN AND MODE OF OCCURRENCE.

Origin of Granites. — All of the rocks here grouped as granites are of course igneous in origin. More particularly, their general coarseness of crystallization and entire lack of any uncrystalline or glassy groundmass indicates that they did not reach the surface of the earth at the time when they cooled and solidified from their original state of fusion. If they had so emerged, they would have been subjected to very rapid cooling; and experience with slags shows that fused rock which cools quickly will take the form either of porous lava-like products or of dense close-grained (or glassy) masses. If, then, the granites had reached the earth's surface while still fused, the resultant quickness of cooling would not have permitted the component minerals to crystallize out completely in relatively large grains.

It is therefore fair to assume that such coarse-grained rocks as the granites cooled while still some distance below the earth's surface; being protected or blanketed from rapid cooling by overlying beds of other rocks. It is true that in many areas granites now appear at the surface, but this is due to the fact that since their cooling and solidification the rock which then overlay them has been worn away and carried off, mostly by the action of surface waters.

Mode of Occurrence. — The chief commercial granites are found as portions of large igneous masses, which at the time of cooling were injected or intruded into other rocks. Through the processes of erosion, these igneous masses now appear at the earth's surface; and in many instances not only the covering rock but the rock which once surrounded them laterally has been removed. In these cases, the granite masses often project above the level of the surrounding country as a boss or dome-shaped hill.

Many of the gneissoid granites which are quarried at various points in the eastern portion of the United States are taken from the ancient stratiform masses alluded to on page 18, as forming the bulk of the Archæan rocks.

MINERAL CONSTITUTION OF GRANITES.

Chief Constituent Minerals. — Most commercial granites consist largely of feldspar and quartz, with commonly lesser amounts

of mica or hornblende; and often with small percentages of other minerals, such as tourmaline, garnet, apatite, rutile, etc. In a few syenites which reach the market — notably the Fourche Mountain granite of Arkansas, — quartz is scarce or lacking; and in this particular Arkansas case the feldspar is replaced by the closely allied minerals *elæolite* and *nepheline*. Likewise, in a few States rather basic rocks are quarried and sold under the name of granite; and in these cases augite is often present, while the feldspar is one of the plagioclases.

In most commercial granites, however, the predominant mineral is feldspar. At times this is orthoclase alone, but commonly some plagioclase feldspar is also present in lesser quantity. Next to the feldspar in abundance is quartz. Mica — either muscovite or biotite, and frequently both — is the third most common constituent; while hornblende occurs less frequently.

Identification of Constituents. — When the minerals in a granite are in grains or crystals sufficiently large to be clearly distinguished, the different essential minerals can usually be identified by use of the following key; which simply embodies in comparative form certain facts noted on previous pages (see pages 25–28).

A. Showing at least one smooth cleavage surface.

I. Separable into thin leaves; readily scratched by knife.

a. Color white, often stained yellow. Mica (*Muscovite*).

b. Color black or brown. Mica (*Biotite*).

II. Not separable into thin leaves.

a. Color light — usually whitish, gray, pink or light green. Feldspar.

b. Color dark green to greenish black. Hornblende or Augite.

B. No smooth surface apparent; fracture rough and glassy; not scratched by knife; color usually light gray to light blue, translucent. Quartz.

Relative Proportions of Minerals. — Considerable industrial as well as scientific interest attaches to a study of the relative proportions in which the various constituent minerals occur in any given granite. There are three ways of determining this. As the three methods differ in ease and in accuracy they will be briefly discussed. They are:

1. *Direct Weighing.* — In this method the sample is coarsely crushed; the different constituent minerals are separated by means of heavy solutions; and the respective proportions are determined by actual weight. This is the most exact and most tedious of the methods.

2. *Chemical Deduction.* — In this method the mineral composition is calculated from the chemical analysis of the sample. The analysis must be of high grade; and errors are necessarily introduced because of certain assumptions which must be made as to the composition of the standard minerals. This method is the second in rank, so far as difficulty is concerned; and under ordinary conditions probably gives the least accurate results of the three.

3. *Surface Measurement.* — In this method the surface areas of the various minerals, as exposed either on a microscope slide or on a polished surface, are measured; and the relative proportions of the various constituents are calculated from these surface measurements. This is the easiest of the methods, and ranks second in accuracy.

Color of Granites. — Most granites of commercial importance are light to dark gray, or reddish in color, though occasionally granites of other colors are marketed. Granites with bluish tints, usually faint, are, for example, seen in certain areas, and a few distinctly greenish granites are on the market. One granite, used in part for an important structure, is quite distinctly yellowish in tint. But these exceptions only serve to emphasize the fact that by far the majority of granites used in any large way are either gray or red.

When the dark minerals biotite, hornblende and ⁶augite are not present in great quantity, the color of a granite is determined largely by the color of the feldspar which it contains.

There is some slight reason for preferring gray or light red granites to others, on the ground of durability, for they are generally composed of minerals which are more resistant to weathering. While granites should be carefully examined to see that the feldspar is fresh and translucent, for a chalky effect is often produced by incipient decay of that mineral. Good yellow granites are extremely rare, for that tint is usually due to the formation of rust through decay of mica (biotite) or some other iron-bearing minerals. Black or greenish granites are apt

to contain large percentages of minerals that are relatively non-resistant to weathering — such as biotite, mica, hornblende, augite, the more basic feldspars, etc.

TABLE 6. — MINERAL COMPOSITION OF AMERICAN GRANITES. (T. N. Dale.)

State.	Locality.	Quartz.	Ortho- clase.	Plagio- clase.	Micas.	Horn- blende.
Maine.....	Jonesport	44.65	28.85	22.45	4.05	
Massachusetts....	Milford	35.66	55.91		8.43	
“	Quincy	30.60	60.02		.....	9.37
“	“	8.43	69.51		.....	22.06
“	“	33.50	56.00		.....	10.50
“	“	33.74	58.79		.....	7.47
“	“	23.01	67.37		.....	9.62
“	“	33.10	55.80		.....	11.10
“	Rockport	35.82	57.97		.....	6.20
“	“	31.95	58.45		.....	9.60
“	“	38.90	55.50		.....	5.60
“	“	33.88	58.86		.....	7.26
“	“	34.70	59.60		.....	5.70
“	Becket	49.35	28.55	15.37	6.57	
New Hampshire ..	Milford	27.09	29.72	34.03	8.58	
“ ..	“	36.76	27.58	29.16	6.50	
“ ..	“	27.40	29.28	27.70	13.51	
“ ..	“	17.10	31.30	45.22	5.74	
“ ..	Conway	31.04	63.15		5.81	
“ ..	Redstone	28.65	65.30		5.55	
“ ..	“	38.26	54.79		6.95	
“ ..	Madison	28.60	67.20		4.20	
Vermont.....	Hardwick	21.75	62.05		16.20	
“	Newark	30.30	64.80		4.64	
“	Randolph	21.20	76.50		2.30	
“	Barre	26.58	65.52		7.90	
“	Woodbury	29.15	64.35		6.48	
“	“	31.22	63.11		5.67	
“	“	27.10	65.60		7.30	
“	Rochester	29.60	62.10		8.30	
Rhode Island.....	Westerly	36.09	28.44	30.63	4.09	
“	“	25.28	20.29	44.48	7.43	
“	“	29.87	35.40	28.35	6.74	

In many cases, however, the selection of stone for a structure rests with the architect, not with the engineer, and this occasionally brings about surprising results. In one instance which came to attention an architect of repute paid special prices to obtain what seemed to him a particularly desirable grade of

stone. He had selected this variety because of its soft yellowish tint, and apparently did not realize that it was simply the weathered phase of a bluish granite, and owed its soft colors to a pretty thorough decay of its feldspar. Such a case is of course exceptional, but the desire for a satisfactory color effect should never be allowed to conflict with the necessity for obtaining a sound stone.

STRUCTURE AND TEXTURE OF GRANITES.

Granites are made up of closely interlocking crystals of various minerals. These crystals may differ greatly in size; they may show fairly definite banding or may be entirely without any orderly arrangement. The granite, considered as a rock mass, may present certain phenomena as to obvious or incipient fracture planes. All of these features require consideration under the present heading.

Coarseness of Crystallization. — Granites vary widely in coarseness of crystallization, from fine-grained rocks in which the individual crystals of quartz and feldspar may be one-fiftieth of an inch or even less in average diameter, up to coarse aggregates in which the quartz and feldspar may average an inch or more in diameter.

The size of grain has an important bearing on the value of the stone for various uses. This effect may be briefly summarized as follows:

1. For monumental work, or where a high polish is desirable, the finest-grained stone is most suitable.
2. For structural work, the medium-grained stones are best adapted.
3. Coarse-grained stone can be used for little except crushed stone.
4. Very coarse-grained stones — the *pegmatites* — may, as later noted, furnish supplies of quartz and feldspar for the pottery and other industries.

Laminated or Gneissoid Structure. — The term *gneiss* is applied to rocks which have the same chemical and mineralogical composition as the granites and their allies, and which from their associations and occurrence are usually known to be of igneous origin; but in which the constituent minerals are arranged in roughly parallel layers or bands.

In a granite, or any other normal igneous rock, the various mineral constituents are scattered through the rock without showing any trace of systematic arrangement; and this lack of arrangement is exactly what would be expected to result when a large mass of fused rock cools down without disturbance from external forces. In places, however, we find rocks of undoubtedly granitic composition and origin, but differing from normal granites in that they show a more or less laminated or



Fig. 14. — Lamination and joint planes in gneiss. (Photo by E. C. Eckel.)

banded structure (Fig. 14). On examination, this is seen to be due to the fact that the constituent minerals (quartz, feldspar, mica, etc.) of these banded or gneissoid granites are arranged in roughly parallel layers. Since these rocks are undoubtedly igneous in origin, this lamination can not have originated in the same way as the beds and layers seen in sedimentary rocks, though the final result is much the same so far as appearance goes. Some further explanation is therefore required as to the origin of this gneissoid structure.

It has been said that the laminated appearance is due to the

fact that the minerals are arranged in parallel layers. This parallelism, in its simplest form, is carried only to the stage that the longer axes of the various mineral crystals are so arranged as to lie in the same plane. In more extreme cases, there has been also some degree of segregation of the different mineral constituents, so that a layer of quartz, practically free from mica or feldspar, will lie next to a layer of mica or feldspar containing practically no quartz.

All of this rearrangement of the minerals, whether it be of the simpler or of the more complex type, must have originated through the action of external stresses on the granite mass, either during its slow cooling from fusion or at a later date. If the latter, it is obvious that almost complete refusion of the rock must have occurred, in order that the gneissoid structure could be produced.

It may be noted here that few granites, even those which show absolutely no trace of lamination when viewed in the mass, have escaped entirely from the effects of strain, either external or internal, occurring during or after their cooling. This is evidenced by the phenomena of rift and grain, referred to in later paragraphs.

Sheet Structure. — In many regions it is noted that granite masses show a more or less irregular division, or tendency to division, into sheets roughly parallel to the exposed surface of the mass (Fig. 15). This sheeting has been ascribed to the effects of temperature changes on the exposed surfaces; and in many cases this explanation is doubtless sufficient. At times, however, evidence is found that similar structures are developed at considerable depths below the surface, and the obvious inadequacy of surface temperatures as causes of deep structural changes has led various geologists to ascribe some or all sheeting structure to strains induced during the original cooling of the mass, or to the effects of later external stresses.

Rift and Grain. — Granite, not being a stratified rock, of course does not possess the bedding planes which practically all of the stratified rocks exhibit, and along which they usually split most readily. The laminated granites or gneisses, it is true, split easily in the planes of their lamination which thus have the same structural effect as the bedding planes of sedimentary rocks.

Even the most massive granites, however, such as show no trace of lamination or gneissoid structure to the eye, are found by the quarryman and stone dresser to break and cut more readily in certain directions than in others. There are commonly two such planes of relatively easy fracture, usually at about right angles to each other. The quarryman speaks of the planes of easiest fracture as the *rift*, and of the other plane as the *grain*.



Fig. 15. — Sheet structure in granite. (Photo by E. C. Eckel.)

The fact that an apparently massive rock does possess such planes of relatively easy fracture seems to depend upon the existence of minute microscopic fractures crossing the rock in the direction of the planes, or in the direction of one of them. These microscopic fractures, which are practically incipient planes of cleavage, may in some cases be due to internal stresses set up during the original cooling of the granite; but in most cases they are probably due to the effect of earth movement on the rock after its cooling.

For more detailed discussion of these phenomena reference may be made to the papers by Dale and others cited below.*

Value of Microscopic Work on Granites. — The examination of a thin section of a granite under the petrographic microscope should result in identifying accurately the component minerals of the stone, and in affording some estimate as to their relative abundance. So far the results are of merely scientific interest, and if microscopic work could produce no further information it might be dispensed with altogether. Fortunately, however, it occasionally affords results which justify its use in the study of a structural granite.

The data which under favorable circumstances may be obtained by the aid of the microscope relate to the physical condition of the component minerals, and of the rock itself. Incipient decay of the feldspars, partial rusting of the iron-bearing minerals and the existence of minute cleavage planes in the rock may be noted by the investigator. All of these data are of a class which possesses economic as well as theoretical interest.

CHEMICAL COMPOSITION OF GRANITES.

Value of Chemical Work on Granites. — The strength of a granite is not directly related to its chemical composition, so that chemical analysis is of no practical importance in determining the possible strength of the stone. It will, however, throw a little light on its other physical properties — for example, the denser granites are usually those lowest in silica — but even then it will be found quicker and less expensive to make specific gravity determinations directly rather than to attempt to infer their results from a chemical analysis.

So far as durability is concerned the case for chemical work is but little stronger, though here also we might draw some rather hazardous conclusions, such, for example, as that the rocks lowest in silica will probably prove less durable than rocks of more acid type.

* Dale, T. N. Rift and grain (in granites). Bull. 313, U. S. Geol. Survey, pp. 26-29, 1907. Also Bull. 354, U. S. G. S., pp. 19-22. 1908.

Tarr, R. S. The phenomena of rifting in granite. Amer. Journal Science, 3d series, vol. 41, pp. 267-272. 1891.

Whittle, C. L. Rifting and grain in granite. Engineering and Mining Journal, vol. 70, p. 161. 1900.

From the purely engineering point of view, therefore, there is but little reason for making a chemical analysis of a granite. If the analysis be a really good one, however, it will be of service in assigning the stone to its proper place in the geological classification. On the other hand, analyses as made and reported by an ordinary laboratory will be of little use to any one or for any purpose.

Normal Chemical Composition of Granite. — The term granite, as used in the stone trade, is construed so broadly that at first sight it might seem impossible to say anything definite concerning the average or normal chemical composition of granite. This has, at any rate, been the attitude taken by most of the writers on this subject.

As a matter of fact, however, a study of the subject will soon prove that the difficulty is more imaginary than real; and that it is due chiefly to a failure to realize that the occurrence of a few abnormal types does not seriously disturb the average result. It is probably safe to say that there is really not much more variation in the composition of commercial granite than there is in the composition of a number of samples of commercial Portland cement. That is to say, if we could sample all of the granite sold in any given year, the range in either direction from the average would not be much greater than in a similar series of cement samples.

The extent of this range in granite composition is well illustrated in the series of tables of granite analyses (Tables 8 to 24). In those tables it is accentuated because of the inclusion of a number of gneisses, syenites, etc. These are marketed as granites, and their analyses are presented for completeness, but it must not be forgotten that the total quantity of such stone sold is unimportant in comparison with the quantity of normal granite.

The following table contains a number of average analyses. The Georgia average is taken from a report by T. L. Watson; all of the other averages were prepared by the present writer. The final average in the last column is merely the arithmetical average of the preceding seven columns — a method of treatment which is accurate enough for our present purposes.

TABLE 7.—AVERAGE COMPOSITION OF GRANITES.

State.....	Maine.	Massachu- setts.	New Jersey.	Vir- ginia.	South Caro- lina.	Georgia.	Wiscon- sin.	Final average.
Number of analyses averaged.	} 7	10	10	6	15	21	7	76
Silica.....	73.02	75.65	73.75	70.79	69.67	69.67	73.72	72.42
Alumina.....	14.89	13.30	13.91	14.04	15.24	16.63	13.38	14.48
Ferric oxide.....	0.83	1.41	1.06	1.90	1.79	1.28	1.60	1.41
Ferrous oxide.....	0.86	0.70	1.23	1.32	2.48	....	1.02	1.09
Lime.....	1.02	0.88	1.27	2.03	1.81	2.13	1.62	1.54
Magnesia.....	0.13	0.06	0.41	0.76	0.66	0.55	0.41	0.43
Potash.....	5.20	4.81	4.51	4.43	4.46	4.71	3.63	4.54
Soda.....	3.44	4.10	3.43	3.63	3.64	4.73	3.17	3.73
Water.....	0.46	0.34	0.27	0.41	0.45	....	0.43	0.34

From the averages in the above table it will be seen that all the striking individual variations are eliminated as soon as even a small group of analyses are averaged. The final average in the last column may be accepted as a fair statement of the normal composition around which granites range.

Composition of American Granites.—The following tables contain analyses of representative American granites, arranged by states.

TABLE 8.—ANALYSES OF GRANITES: MAINE.

	1	2	3	4	5	6	7	Aver- age.
Silica.....	73.02	74.64	71.54	73.48	74.54	70.94	72.97	73.019
Alumina.....	16.22	14.90	14.24	15.26	13.30	15.68	14.63	14.890
Ferric oxide.....	2.59	1.56	0.74	1.42	0.92	....	....	0.83
Ferrous oxide.....	....	....	1.18	....	0.79	2.29	1.73	0.857
Lime.....	0.94	0.39	0.98	0.88	1.26	1.23	1.48	1.023
Magnesia.....	tr	tr	0.34	0.09	0.01	0.19	0.27	0.131
Potash.....	3.42	6.88	4.73	5.66	5.01	5.54	5.18	5.203
Soda.....	3.60	0.41	3.39	3.12	3.69	3.58	3.28	3.439
Water.....	....	....	0.61	....	0.55	0.37	0.33	0.465

1. Blue Hill, Hancock County; Ricketts & Banks, analyst; 20th Ann. Rep. U. S. G. S., pt. 6, p. 393.

2. Blue Hill, Hancock County; H. J. Williams, analyst; 20th Ann. Rep. U. S. G. S., pt. 6, p. 393.

3. North Jay, Franklin County; E. T. Rogers, analyst; 20th Ann. Rep. U. S. G. S., pt. 6, p. 392.
4. Waldsboro, Lincoln County; Ricketts & Banks, analyst; 20th Ann. Rep. U. S. G. S., pt. 6, p. 391.
5. High Isle, Knox County; J. F. Kemp, analyst; Bull. 313, U. S. G. S., p. 122.
6. Hurricane Island, Knox County; Ricketts & Banks, analyst; Bull. 313, U. S. G. S., p. 137.
7. Jonesboro, Washington County; Ricketts & Banks, analyst; Bull. 313, U. S. G. S., p. 170.

TABLE 9.—ANALYSES OF GRANITES: MASSACHUSETTS.

	1	2	3	4	5	6	7	8	9	10	Average.
Silica	76.07	76.95	69.46	81.05	77.08	72.07	75.77	76.52	73.93	77.61	75.651
Alumina ..	12.67	11.15	17.50	14.70	12.54	14.43	13.59	12.21	12.29	11.94	13.302
Ferric ox. .	2.00	0.25	2.30	2.71	0.95	1.25	1.14	.....	2.91	0.55	1.406
Ferrous ox. ....	.....	0.55	.....	.....	.....	0.89	0.52	2.66	1.55	0.87	0.704
Lime	0.85	tr.	2.57	1.10	0.75	1.18	0.94	0.79	0.31	0.31	0.881
Magnesia .	0.10	tr.	0.31	tr.	0.01	tr.	tr.	0.13	0.04	tr.	0.064
Potash ...	4.71	5.03	4.07	n.d.	4.99	5.41	n.d.	4.68	4.63	4.98	4.813
Soda	3.37	5.60	3.01	n.d.	3.64	5.85	n.d.	2.86	4.66	3.80	4.100
Water .....	.....	0.20	0.82	0.44	.....	0.35	0.49	0.41	0.41	0.23	0.335

1. Milford, Worcester County; C. F. Chandler, analyst; 20th Ann. Rep. U. S. G. S., pt. 6, p. 404.
2. Milford, Worcester County; H. P. Talbott, analyst; 20th Ann. Rep. U. S. G. S., pt. 6, p. 403.
3. Chester, Hampden County; J. F. Kemp, analyst; 18th Ann. Rep. U. S. G. S., pt. 5, p. 965.
4. Cape Ann, Essex County; Watertown Arsenal, analyst; 20th Ann. Rep. U. S. G. S., pt. 6, p. 402.
5. Milford, Worcester County; L. P. Kinnicutt, analyst; Min. Res. U. S., 1903, pamphlet ed., p. 119.
6. Milford, Worcester County; R. H. Richards, analyst; Min. Res. U. S., 1903, pamphlet ed., p. 119.
7. Milford, Worcester County; R. H. Richards, analyst; Min. Res. U. S., 1903, pamphlet ed., p. 119.
8. Milford, Worcester County; R. C. Sweetzer, analyst; Bull. 354, U. S. Geol. Surv., p. 88.
9. Quincy, Mass.; H. S. Washington, analyst; Bull. 354, U. S. Geol. Surv., p. 93.
10. Rockport, Mass.; H. S. Washington, analyst; Bull. 354, U. S. Geol. Surv., p. 123

TABLE 10.—ANALYSES OF GRANITES: NEW HAMPSHIRE.

	1	2	3	4	5	6
Silica.....	73.15	72.47	71.44	70.42	66.80	74.47
Alumina.....		16.17	14.72	14.64	18.29	14.15
Ferric oxide }	17.04	....	2.39	1.54	....	1.16
Ferrous oxide }		0.41	0.46	2.34	5.35	1.21
Lime.....	0.81	1.65	tr.	tr.	1.70	1.70
Magnesia.....	0.30	0.14	0.96	1.20	....	0.63
Potash.....	5.74	4.83	0.89	0.71	1.77	4.14
Soda.....	2.05	3.43	7.66	7.80	6.09	1.97
Water.....	....	....	....	....	....	0.26

1. Troy, Cheshire County; L. P. Kinnicutt, analyst; 20th Ann. Rep. U. S. Geol. Surv., pt. 6, p. 418.
2. Mason, Hillsboro County; Ricketts & Banks, analysts; 20th Ann. Rep. U. S. Geol. Surv., pt. 6, p. 418.
3. Redstone, Carroll County; F. C. Robinson, analyst; 20th Ann. Rep. U. S. Geol. Surv., pt. 6, p. 417.
4. Redstone, Carroll County; F. C. Robinson, analyst; 20th Ann. Rep. U. S. Geol. Surv., pt. 6, p. 417.
5. Lancaster, Coos County; E. R. Angell, analyst; Min. Res. U. S., 1903, pamphlet ed., p. 136.
6. Concord; Sherman & Edwards, analysts; Bull. 354, U. S. G. S., p. 150.

TABLE 11.—ANALYSES OF GRANITES: CONNECTICUT.

	1	2	3	4
Silica (SiO ₂).....	68.40	72.73	72.06	68.11
Alumina (Al ₂ O ₃).....	15.75		14.83	14.28
Ferric oxide (Fe ₂ O ₃).....	2.97	16.95	1.28	
Ferrous oxide (FeO).....	0.65		0.64	2.63
Lime (CaO).....	1.64	1.05	1.20	1.86
Magnesia (MgO).....	0.12	tr.	0.13	0.68
Potash (K ₂ O).....	5.78	8.15	5.64	5.46
Soda (Na ₂ O).....	4.16	0.90	4.31	6.57
Water above 100° C. }				
Water below 100° C. }	0.48	0.22	0.65	n.d.

1. Millstone Point, H. T. Vulté, analyst.
 2. Red granite Co., quarry, Stony Creek,
L. P. Kinnicutt, analyst.
 3. Brooklyn Quarry, Stony Creek,
H. T. Vulté, analyst.
 4. Booth Bros. quarry, Waterford; Ricketts & Banks, analysts; 20th Ann. Rep. U. S. G. S., pt. 6., p. 364.
- } Bulletin Geol. Soc. America,
vol. 10, p. 375.

TABLE 12.—ANALYSES OF GRANITES: VERMONT.

	1	2	3
Silica.....	69.56	77.52	69.89
Alumina.....	15.38	16.78	15.08
Ferric oxide.....	2.65	0.84	1.04
Ferrous oxide.....	....	....	1.46
Lime.....	1.76	2.56	2.07
Magnesia.....	tr.	0.32	0.66
Potash.....	4.31	0.62	4.29
Soda.....	5.38	1.21	4.73
Water.....	1.02	0.33	0.54

1. Barre, Washington County; W. C. Day, 20th Ann. Rep. U. S. Geol. Surv., pt. 6, p. 445.
2. Bethel, Windsor County; C. S. McKenna; Min. Res. U. S., 1903, p. 177.
3. Barre, G. I. Finlay, Rept. Vt. State Geol. for 1902, p. 55.

TABLE 13.—ANALYSES OF GRANITES: RHODE ISLAND.

	1	2	3
Silica (SiO_2).....	71.23	71.64	73.05
Alumina (Al_2O_3).....	13.65	15.66	14.53
Titanic oxide (Fe_2O_3).....	0.21		
Ferric oxide (Fe_2O_3).....	1.70 }	2.34	2.96
Ferrous oxide (FeO).....	1.00 }		
Manganous oxide (MnO).....	0.05	tr.	tr.
Lime (CaO).....	2.31	2.70	2.06
Magnesia (MgO).....	0.75	tr.	tr.
Potash (K_2O).....	3.79	5.60	5.39
Soda (Na_2O).....	3.55	1.58	1.72
Water above 100°C . }	1.72	0.48	0.29
Water below 100°C . }			

1. Conanicut Island, L. V. Pirsson, analyst.
 2. Gray, Westerly, }
 3. Red, Westerly, }
- F. W. Love, analyst. } Bulletin Geol. Soc. America,
vol. 10, p. 378.

TABLE 14.—ANALYSES OF GRANITES: NEW YORK, PENNSYLVANIA, AND DELAWARE.

Constituent.	1	2	3	4	5
Silica.....	63.19	66.72	69.10	74.84	67.98
Alumina.....	10.50	16.15	14.69	18.90	15.14
Ferric oxide.....	10.97 }	3.42	{ 4.63	3.69 }	4.39
Ferrous oxide.....	1.51 }		{ n.d. }	
Lime.....	6.12	2.30	1.90	1.54	5.89
Magnesia.....	1.44	0.73	0.68	0.92	0.53
Potash.....	4.02	5.66 }	9.00	.....	{ 0.45
Soda.....	1.92	4.36 }			{ 4.32
Water.....	0.19	0.77	.....	.....	0.30

1. Hornblende diorite. Iona Island, N. Y. J. F. Geiste, analyst. 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 421.
2. Augite syenite. Little Falls, Herkimer County, N. Y. E. W. Morley, analyst.
3. Hadley, Saratoga County, N. Y. Pittsburg Testing Laboratory, analyst. Min. Res. U. S. for 1903.
4. Ridley Park, Chester County, Pa. Solvay Company, analyst. Min. Res. U. S. for 1903.
5. Augustine, Newcastle County, Delaware. Booth, Garrett & Blair, analyst. Min. Res. U. S. for 1903.

TABLE 15.—ANALYSES OF GRANITES: NEW JERSEY.

	1	2	3	4	5	6	7	8	9	10	Average.
Silica (SiO ₂) .	71.91	77.59	74.36	75.56	69.48	75.02	75.15	74.70	68.60	75.17	73.754
Alumina (Al ₂ O ₃)	15.71	10.53	12.75	12.61	16.42	13.73	14.65	15.45	14.72	12.55	13.912
Ferric oxide (Fe ₂ O ₃) . . .	0.21	0.21	2.09	0.64	0.56	0.83	0.11	0.08	4.29	1.54	1.056
Ferrous oxide (FeO)	0.13	1.74	1.35	1.16	2.60	0.99	0.90	0.64	1.41	1.41	1.233
Lime (CaO) .	0.70	0.76	0.82	0.84	3.45	0.88	0.92	1.70	1.46	1.15	1.268
Magnesia (MgO)	0.03	1.01	0.11	0.05	1.15	0.03	0.04	0.06	0.38	0.21	0.407
Potash (K ₂ O)	8.60	5.30	3.76	5.93	1.18	4.74	4.71	2.62	3.52	4.62	4.506
Soda (Na ₂ O) .	2.61	1.58	3.44	2.35	4.59	3.36	3.60	4.90	4.82	3.07	3.432
Water (H ₂ O) .	0.27	0.60	0.20	0.42	0.34	0.17	0.24	0.10	0.16	0.22	0.272

Analyses 1-10 by R. B. Gage. Quoted from An. Rep. State Geologist, N. J., for 1908.

1. Coarse grained pink granite, Pompton Junction.
2. Gneiss inclusions in preceding granite.
3. Gray gneissoid granite, di Laura's quarry, near Haskell.
4. Pinkish granite-gneiss, Charlotteburgh.

5. Dark gray granite, Malley's quarry, Morris Plains.
6. Reddish granite-gneiss, Allen quarry, Waterloo.
7. Whitish granite-gneiss, quarry two miles north of Waterloo.
8. White granite-gneiss, D. L. & W. R. R. quarry south of Cranberry Lake.
9. Gray granite, Kice's quarry, north of German Valley.
10. Light gray gneiss, Kice's quarry, west of German Valley.

TABLE 16. — ANALYSES OF GRANITES: MARYLAND.

	1	2	3	4	5	6	7
Silica	74.87	72.57	71.79	71.45	70.45	66.68	62.91
Alumina	14.27	15.11	15.00	14.36	15.98	14.93	19.13
Ferric oxide .....	.....	0.59	0.77	2.07	0.75	1.58	0.98
Ferrous oxide	0.51	1.02	1.12	2.78	1.84	3.32	3.20
Lime	0.48	1.65	2.50	1.58	2.60	4.89	4.28
Magnesia	0.16	0.30	0.51	1.17	0.77	2.19	1.00
Potash	5.36	4.33	4.75	3.28	3.59	2.05	3.38
Soda	3.06	3.92	3.09	1.95	3.83	2.65	3.94
Water	0.92	0.47	0.64	1.30	0.45	1.25	0.63

All of the above analyses are by W. F. Hillebrand, and are quoted from 15th An. Rep. U. S. Geol. Survey, page 672. The localities were as follows:

1. White granite, Brookville, Montgomery County.
2. Biotite-muscovite granite, Guilford, Howard County.
3. Biotite granite, Woodstock, Baltimore County.
4. Biotite granite, Sykesville, Carroll County.
5. Biotite granite, Dorsey Run Cut, Howard County.
6. Biotite granite, Rowlandsville, Cecil County.
7. Biotite granite, Dorsey Run Cut, Howard County.

TABLE 17. — ANALYSES OF GNEISSES: MARYLAND AND DISTRICT OF COLUMBIA.

	1	2	3	4	5
Silica	73.69	69.33	67.22	63.43	78.28
Alumina	12.89	14.33	15.34	16.69	9.96
Ferric oxide	1.02	.....	2.78	3.36	1.85
Ferrous oxide	2.59	3.60	3.41	3.87	1.78
Lime	3.74	3.21	1.36	0.80	1.68
Magnesia	0.50	2.44	1.65	2.33	0.95
Potash	1.48	2.67	3.26	3.22	1.35
Soda	2.81	2.70	2.00	2.38	2.73
Water	1.06	1.22	1.97	2.90	0.95

1. Biotite gneiss, Port Deposit, Cecil County, Md. Wm. Bromwell, analyst. 20th Ann. Rep. U. S. Geol. Surv., pt. 6, p. 399.
2. Biotite gneiss, Broad Branch quarry, District of Columbia. W. F. Hillebrand, analyst; 15th An. Rep. U. S. Geol. Surv., p. 672.

3. Potomac Stone Company quarry, below Chain Bridge, D. C. Ibid, p. 670.
4. Emery's Store, Cabin John Bridge, Montgomery County, Md. Ibid, p. 670.
5. Great Falls, Montgomery County, Md. Ibid, p. 670.

TABLE 18.—ANALYSES OF GRANITES: VIRGINIA.

	1	2	3	4	5	6	7	8	9	10	Average of 1-8.
Silica.....	72.27	71.51	71.19	70.83	69.48	69.44	69.29	68.45	60.52	58.32	70.787
Alumina..	14.30	13.82	14.01	12.70	13.95	15.46	14.07	10.00	16.99	15.77	14.04
Ferric ox.	1.16	1.76	1.66	2.67	2.82	1.31	2.59	5.71	0.60	6.56	1.897
Ferrous ox.	0.97	1.20	1.29	1.36	1.70	1.43	2.03	2.59	6.53	0.59	1.325
Lime.....	1.56	1.79	2.04	1.88	2.81	2.11	2.67	6.20	4.58	11.58	2.032
Magnesia..	0.70	0.80	0.14	0.53	1.10	1.01	1.32	3.26	1.59	0.09	0.763
Potash...	5.00	4.63	4.45	4.83	3.45	4.25	2.87	1.18	3.91	4.01	4.435
Soda.....	3.45	3.64	3.56	3.49	3.65	3.97	2.89	1.98	2.83	0.32	3.628
Water....	0.29	0.48	0.37	0.41	0.54	0.36	0.43	0.80	0.88	1.73	0.408

All the above analyses are quoted from Bulletin 426, U. S. Geol. Survey, pages 72 and 78. Analyses 1 to 8 inclusive are by M. W. Thornton; analyses 9 and 10 by W. C. Phalen. The localities are as follows:

1. Biotite granite, Westham quarries, Richmond, Chesterfield County.
2. Biotite granite, Petersburg Granite Co., Petersburg, Dinwiddie County.
3. Biotite granite, McGowan quarry, Chesterfield County.
4. Biotite granite, Netherwood quarry, Chesterfield County.
5. Biotite granite, Cartwright and Davis quarries, Fredericksburg, Spottsylvania County.
7. Biotite gneiss, Middendorf quarry, Manchester, Chesterfield County.
8. Biotite gneiss, Cartwright and Davis quarries, Fredericksburg, Spottsylvania County.
9. Pyroxene syenite, Milams Gap, Page County.
10. Epidote granite, Milams Gap, Page County.

TABLE 19.—ANALYSES OF GRANITES: NORTH CAROLINA.

	1	2	3	4	5	6
Silica.....	75.92	75.14	71.56	70.70	69.28	66.01
Alumina.....	14.47	n.d.	16.79	n.d.	17.44	n.d.
Ferric oxide.....	0.88	n.d.	1.87	n.d.	1.08	n.d.
Ferrous oxide.....	....	n.d.	.....	n.d.	1.22	n.d.
Lime.....	0.02	0.93	2.93	2.96	2.30	1.44
Magnesia.....	0.09	n.d.	0.30	n.d.	0.27	n.d.
Potash.....	4.01	2.57	11.96	{ 2.45 4.56	2.76	3.16
Soda.....	4.98	5.82			3.64	5.06
Water.....	0.64	n.d.	n.d.	n.d.	n.d.	n.d.

1. Quartz porphyry; Charlotte, Mecklenburg County; Genth, analyst; Geology of North Carolina, Vol. 1, p. 124.
2. Pink Granite Company, quarry, Dunn's Mt., Rowan County, Bull. 426, U. S. Geol. Surv., p. 117.
3. Granite; Mount Airy, Surry County; C. M. Cresson, analyst; 18th An. Rep. U. S. Geol. Surv., pt. 5, p. 970.
4. Granite; Mount Airy, Surry County; Bull. 426, U. S. Geol. Surv., p. 117.
5. Granite; Raleigh, Wake County; Hanna, analyst; Geology of North Carolina, vol. 1, p. 302.
6. Granite; Johnson quarry, Mooresville, Iredell County; Bull. 426, U. S. G. S., p. 117.

TABLE 20. — ANALYSES OF GRANITES: SOUTH CAROLINA.

	1	2	3	4	5	6	7	8	9	10
Silica.....	68.70	68.71	68.80	68.90	69.52	69.74	70.11	70.20	70.54	70.77
Alumina.....	15.49	15.41	15.73	15.75	16.77	13.72	15.76	14.22	14.56	14.89
Ferric oxide..	1.10	1.85	2.14	1.16	0.95	3.64	{ 1.07	1.14	1.06	0.75
Ferrous oxide.	3.73	1.59	1.57	1.49	1.56						{ 1.76	1.24	1.62	1.24
Lime.....	1.70	1.64	1.64	2.66	1.82	1.54	1.84	2.14	1.28	2.08
Magnesia.....	0.86	1.25	1.16	0.74	0.75	0.22	0.62	0.48	0.78	0.43
Potash.....	3.36	4.61	4.54	3.49	4.10	4.98	4.27	4.82	5.37	4.70
Soda.....	3.09	3.48	3.45	4.76	3.43	5.39	3.39	5.39	3.97	4.47
Water.....	0.81	0.34	0.33	0.18	1.43	.....	0.45	0.33	0.27	0.19

	11	12	13	14	15	16	17	18	19	Average.
Silica.....	70.90	71.20	72.19	72.22	73.26	62.34	65.72	68.15	73.10	70.384
Alumina..	15.25	17.04	14.06	14.51	15.39	17.22	17.22	14.30	13.82	15.237
Ferric ox.	1.52	3.48	{ 0.70 1.28 }		1.24	{ 1.75 1.70 }		2.44		0.93
Ferrous ox.	1.53		{ 1.80 1.52 }			{ 2.49 2.67 }		2.49		1.43
Lime.....	2.40	n.d.	1.88	1.32	1.36	3.28	2.80	2.80	1.72	1.807
Magnesia.	0.63	0.11	0.84	0.58	0.38	1.30	1.45	1.04	0.51	0.655
Potash. .	2.85	4.70	3.94	4.30	6.89	5.14	3.80	3.84	5.06	4.461
Soda.....	4.32	2.32	3.46	3.21	0.55	5.28	3.68	3.80	3.04	3.645
Water....	0.17	0.63	0.18	0.52	n.d.	0.28	0.35	0.28	0.23	0.448

All of the above analyses are quoted from Bulletin 426, U. S. Geol. Survey, pages 174-175. The localities are as follows:

1. Porphyritic biotite granite, Clouds Creek, near Batesburg, Saluda County.
2. Porphyritic biotite granite, Flat Rock, Kershaw County.
3. Biotite granite, Cold Point Station, Laurens County.
4. Biotite granite, Jackson quarry, Clover, York County.
5. Biotite granite, Leitzsey quarry, Newberry, Newberry County.
6. Biotite granite, Anderson quarry, Rion, Fairfield County.
7. Biotite granite, Excelsior quarry, Heath Springs, Lancaster County.

8. Biotite granite, Flatrock quarry, Carlisle, Union County.
9. Biotite granite, Benjamin quarry, Greenwood, Greenwood County.
10. Muscovite-biotite granite, Whiteside quarry, Filbert, York County.
11. Muscovite-biotite granite, Blair, Fairfield County.
12. Biotite granite, Keystone Granite Company, Pacolet, Spartanburg County.
13. Biotite granite, Ross quarry, Columbia, Lexington County.
14. Biotite granite, Southern Granite Company, Heath Springs, Kershaw County.
15. Biotite granite, Winnsboro Granite Company, Rion, Fairfield County.
16. Biotite gneiss, Hancel quarry, Pendleton, Anderson County.
17. Biotite gneiss, Ware Shoals, Laurens and Abbeville Counties.
18. Biotite gneiss, Beverly, Pickens County.
19. Biotite gneiss, Bates quarry, Batesburg, Lexington County.

TABLE 21.—ANALYSES OF GRANITES: GEORGIA.

	1	2	3	4	5	6	7	8	9	10
Silica.....	72.56	71.00	70.38	70.30	70.18	70.03	69.88	69.74	69.64	69.55
Alumina.....	14.81	16.33	16.47	16.17	17.30	15.62	16.42	16.72	17.21	16.72
Ferric oxide.....	0.94	1.12	1.17	1.19	1.20	1.31	1.96	1.45	1.32	0.99
Lime.....	1.19	1.83	1.72	2.61	2.03	2.45	1.78	1.93	2.14	1.69
Magnesia.....	0.20	0.35	0.31	0.31	0.64	0.52	0.36	0.36	0.66	0.27
Potash.....	5.30	4.65	5.62	4.88	4.77	5.42	5.63	5.33	4.95	3.94
Soda.....	4.94	4.80	4.98	4.72	4.36	4.22	4.45	4.84	4.53	5.88
Water.....	0.70	0.87	0.31	0.63	0.35	0.77	0.39	0.47	0.35	0.27
	11	12	13	14	15	16	17	18	19	20
Silica.....	69.53	69.45	69.36	69.34	69.25	69.08	69.07	68.81	68.79	68.76
Alumina.....	16.46	15.93	17.23	17.01	16.04	17.67	16.56	17.67	16.48	16.80
Ferric oxide.....	1.15	1.31	1.43	1.74	1.72	1.41	1.37	1.13	0.98	0.99
Lime.....	2.10	1.91	2.14	2.77	1.89	3.27	1.83	2.17	1.76	2.72
Magnesia.....	0.85	0.55	0.59	0.61	0.31	0.64	0.76	0.50	1.30	1.00
Potash.....	4.91	5.16	4.57	4.54	4.94	3.29	5.02	3.90	5.85	3.70
Soda.....	5.00	4.33	5.17	4.69	4.52	4.56	4.65	4.97	4.74	4.82
Water.....	0.91	0.50	0.33	0.26	0.43	0.56	0.92	0.30	0.38	0.29
	21	22	23	24	25	26	27	28	29	30
Silica.....	68.38	66.92	63.27	70.90	70.88	70.24	69.77	69.48	69.37	69.17
Alumina.....	17.79	18.19	19.93	15.86	15.86	16.78	17.05	16.64	16.99	16.47
Ferric oxide.....	1.21	3.05	2.82	1.37	1.77	1.46	1.60	1.84	1.99	1.22
Lime.....	2.85	4.95	2.89	2.15	1.79	2.00	2.21	2.32	2.03	2.02
Magnesia.....	0.72	1.25	0.49	0.02	0.93	0.76	0.99	0.29	0.84	0.61
Potash.....	3.57	2.02	4.85	4.62	4.64	5.03	4.08	4.49	4.54	4.41
Soda.....	4.36	3.83	4.14	5.05	3.94	3.70	3.97	4.74	3.44	4.89
Water.....	0.78	0.46	0.86	0.50	0.49	0.50	0.44	0.46	0.55	1.06

TABLE 21 (Continued)

	31	32	33	34	35	36	37	38	39	40
Silica.....	69.13	67.62	66.31	63.65	76.37	76.00	75.89	75.45	75.16	74.96
Alumina.....	17.14	16.29	18.27	20.46	13.31	13.11	14.02	13.71	13.74	13.71
Ferric oxide.....	1.52	2.31	2.51	2.20	1.21	0.92	0.71	0.92	0.91	0.90
Lime.....	1.85	2.37	2.91	3.38	1.13	1.06	0.70	0.94	0.91	1.02
Magnesia.....	0.79	0.78	1.22	1.50	0.10	0.27	0.12	0.18	0.17	0.24
Potash.....	5.49	4.58	4.09	4.58	3.68	4.69	5.56	4.30	5.05	4.79
Soda.....	4.06	5.42	3.69	4.75	4.02	3.88	3.64	3.87	3.76	4.68
Water.....	0.52	0.32	0.61	0.42	0.20	0.31	0.28	0.40	0.32	0.44

	41	42	43	44	45	46
Silica.....	74.80	73.95	72.96	71.20	69.51	68.89
Alumina.....	15.46	14.23	14.70	15.46	16.32	16.47
Ferric oxide.....	1.04	1.29	1.28	1.17	2.38	2.34
Lime.....	0.82	1.07	1.28	1.36	1.84	1.63
Magnesia.....	0.11	0.23	0.07	0.38	1.28	0.40
Potash.....	2.52	5.29	4.73	5.30	3.47	4.15
Soda.....	4.80	4.61	4.18	4.96	3.82	4.38
Water.....	0.31	0.25	0.23	0.52	1.11	0.32

Analyses 1 to 46 of the preceding table are quoted from Watson's report on the granites of Georgia, published as Bulletin 9, Georgia Geological Survey. All were made by T. L. Watson, on samples collected by himself. Nos. 1 to 23 inclusive are of normal granites; Nos. 24 to 34 are of porphyritic granites; and Nos. 35 to 46 of gneisses. The localities from which the various samples were taken are as follows:

1. Stone Mountain, DeKalb County.
2. Fortson quarry, near Goss, Elbert County.
3. Coggins Granite Company, near Elberton, Elbert County.
4. Diamond Blue Granite Company, Hutchins, Oglethorpe County.
5. Brown-Deadwyler quarry, in Madison County.
6. Lexington Blue Granite Company quarry, Oglethorpe County.
7. Greenville Granite County quarry, Meriwether County.
- 8, 9. Coggins Granite Company quarry, near Oglesby, Elbert County.
10. Carmichael quarry, Fairburn, Campbell County.
11. Hutchins, Oglethorpe County.
12. Swift & Wilcox quarry, Elberton, Elbert County.
13. Childs quarry, Oglesby, Elbert County.
14. Lynch quarry, Eatonton, Putnam County.
15. Tate & Oliver quarry, Elberton, Elbert County.
16. Cole quarry, Newman, Coweta County.
17. Overby quarry, Coweta County.
18. Echols Mill, Oglethorpe County.
19. Hill quarry, Newman, Coweta County.
20. Turner quarry, Griffin, Spalding County.

21. Camak, Warren County.
22. Grantville, Coweta County.
23. Tigner quarry, Odessa, Meriwether County.
24. Georgia Quincy Granite Company quarry, Sparta, Hancock County.
25. Lime Creek, Fayette County.
26. Flat Rock, Pike County.
27. Heggie Rock, Columbia County.
28. Sparta quarry, Hancock County.
29. Milledgeville, Baldwin County.
30. Moseley quarry, East Point, Fulton County.
31. Greensboro, Greene County.
32. Rocker quarry, Hancock County.
33. Brinkley property, Warren County.
34. McCollum quarry, Coweta, Coweta County.
35. Odessa quarry, Meriwether County.
36. Crossley quarry, Lithonia, Dekalb County.
37. Snell quarry, Snellville, Gwinnett County.
38. Tilley quarry, Rockdale County.
39. Arabia Mountain, Lithonia, Dekalb County.
40. Flat Rock, near Franklin, Heard County.
41. Flat Shoals, Meriweather Co.
42. Flat Rock, Coweta County.
43. Southern Granite Company quarry, Lithonia, Dekalb County.
44. Freeman quarry, Covington, Newton County.
45. Athens, Clarke County.
46. McElvaney Shoals, Gwinnett County.

TABLE 22.—ANALYSES OF GRANITES: ARKANSAS,
MISSOURI AND OKLAHOMA.

Constituent.	1	2	3	4	5	6	7	8	9
Silica.....	60.03	59.62	59.70	72.35	71.88	71.33	69.94	77.05	65.30
Alumina.....	20.76	18.67	18.85	13.78	12.88	12.55	15.19	11.77	19.94
Ferric oxide.....	4.01	5.07	4.85	1.87	3.05	3.75	1.88	2.33	2.60
Ferrous oxide.....	0.75	.....	.....	0.36	1.05	0.85	0.60	n.d.	....
Lime.....	2.62	1.80	1.34	0.87	1.13	0.94	1.15	2.21	4.50
Magnesia.....	0.80	0.84	0.68	0.42	0.33	0.58	0.92	n.d.	1.00
Potash.....	5.48	5.65	5.97	4.49	4.46	4.20	4.29	3.88	} 4.37
Soda.....	5.96	6.95	6.29	4.44	4.21	4.52	3.95	2.90	
Water.....	.....	0.80	1.88	0.76	0.43	0.42	0.99	0.52	0.30

1. Elæolite syenite, Fourche Mt., Ark.; R. N. Brackett, analyst; An. Rep. Ark. Geol. Sur. for 1890, vol. 2, p. 39.
2. Elæolite syenite, Bauxite Station, Ark.; W. A. Noyes, analyst; An. Rep. Ark. Geol. Sur. for 1890, vol. 2, p. 135.
3. Elæolite syenite, Fourche Mt., Ark.; W. A. Noyes, analyst; An. Rep. Ark. Geol. Sur. for 1890, vol. 2, p. 181

4. Granite, Ironton, Mo.; W. Melville, analyst; Prof. Paper, No. 14, U. S. Geol. Sur., p. 147.
- 5, 6. Quartz porphyry, Ironton, Mo.; W. Melville, analyst; Ibid.
7. Granite, Ironton, Mo.; Ibid, p. 161.
8. Granite, Graniteville, Mo.; W. Melville, analyst; 18th An. Rep. U. S. Geol. Sur., pt. 5, p. 968.
9. Tishomingo, Oklahoma; Min. Resources U. S., for 1903.

TABLE 23.—ANALYSES OF GRANITE: WISCONSIN.

	1	2	3	4	5	6	7	Average.
Silica (SiO ₂).....	76.54	66.10	75.40	74.62	76.62	73.65	73.09	73.717
Alumina (Al ₂ O ₃)...	13.82	20.82	11.34	10.01	13.02	11.19	13.43	13.376
Ferric oxide (Fe ₂ O ₃)	1.62	1.52	4.16	3.85	1.01	1.31	2.57	1.604
Ferrous oxide.....	....	2.17	....	1.72	....	3.25	....	1.020
Lime.....	0.85	1.57	0.90	2.43	0.51	2.78	2.29	1.619
Magnesia.....	0.01	0.95	....	0.33	0.05	0.51	1.03	0.412
Potash.....	2.31	3.48	6.44	3.38	6.38	1.86	1.58	3.633
Soda.....	4.32	2.94	1.76	3.33	2.24	3.74	3.85	3.169
Water.....	0.20	0.54	....	0.24	....	0.44	0.72	0.428

1. Wausau, W. W. Daniells, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
2. Athelstane, W. W. Daniells, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
3. Montello, F. G. Weichmann, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
4. Waushara, S. Weidman, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
5. Waushara, Milwaukee Monument Company, A. S. Mitchell, analyst; Min. Res. U. S., 1903, p. 204.
6. Berlin, S. Weidman, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
7. Uttley, S. Weidman, analyst; Bull. 4, Wis. Geol. Sur., p. 420.

TABLE 24.—ANALYSES OF GRANITE: WESTERN AND PACIFIC STATES.

Constituent.	1	2	3	4	5	6	7	8	9
Silica.....	75.35	61.47	58.67	68.50	71.78	68.24	71.70	71.98	67.45
Alumina.....	13.69	23.02	14.89	17.02	14.75	16.30	14.54	15.07	13.04
Ferric oxide }	3.94	4.46	7.56	3.25	....	1.37	1.46	1.97	5.56
Ferrous oxide }	....	....	....	....	1.94	2.13	1.80	0.82	2.78
Lime.....	2.97	5.59	5.68	4.00	2.36	3.20	3.13	2.46	4.68
Magnesia.....	0.06	trace	1.79	1.58	0.71	1.88	0.39	0.58	2.65
Potash.....	2.85	1.22	2.69	2.10	4.89	6.30	6.06	6.92	3.57
Soda.....	1.14	4.09	7.69	3.55	3.12		6.06	6.92	3.57
Water.....	100.00	....	0.57	....	0.52	0.24	0.92	0.20	0.27

1. Exeter, Tulare County, Calif.; Watertown Arsenal, analyst; Min. Res. U. S., 1903.
2. Snake River, Nez Percés County, Idaho; W. C. Day, analyst; Min. Res. U. S., 1903.

3. Reno, Washoe County, Nevada; J. W. Phillips, analyst; 20th An. Rep. U. S., pt. 6, p. 416.
4. Haines, Baker County, Oregon; Watertown Arsenal, analyst; Min. Res. U. S., 1903.
5. Little Cottonwood Canyon, Utah; T. M. Drown, analyst; Reports Fortieth Parallel Survey, vol. 2, p. 356.
6. Medical Lake, Washington; R. W. Thatcher, analyst; vol. 2, Reports Washington Geol. Sur., p. 141.
7. Snake River, Washington; *ibid.*
8. Little Spokane River, Washington; *ibid.*
9. Index, Washington; *ibid.*

PHYSICAL PROPERTIES OF GRANITES.

Density.—Data regarding the specific gravity and weight per cubic foot of granites are available in sufficient quantity to serve as bases for general conclusions. With regard to absorption and porosity this is not the case, for here the methods of testing differ so widely that no general comparisons can be made.

TABLE 25.—AVERAGE SPECIFIC GRAVITY AND WEIGHT OF GRANITES.

Results averaged.	Specific gravity.			Weight per cubic foot, average.
	Minimum.	Average.	Maximum.	
12 New England granites.....	2.618	2.644	2.671	
17 Georgia granites.....	2.645	2.677	2.739	
14 Wisconsin granites.....	2.629	2.655	2.713	
Final results, average.....	2.618	2.659	2.739	165.92

Compressive Strength of Granites.—In a preceding section it was noted that the variations in chemical analyses of granites seemed, at first sight, to be so great as to defy any attempt to generalize concerning normal composition; but that careful examination showed that the difficulty was not insurmountable. The same things can be said, with equal truth, regarding the compressive strength of granites.

In the table (Table 27) presented later, the results of compression tests on seventy-five American granites are tabulated. These present wide variations, the lowest test reported in the table showing only 5657 pounds per square inch, while the

highest result is 47,674 pounds. If we take the column of averages, however, it is soon found that these extreme results* do not fairly represent the situation. In the following table the tests are grouped into classes, according to average results.

TABLE 26. — AVERAGE COMPRESSIVE STRENGTH OF GRANITES.

Class.	Number of tests.
Below 15,000 lbs. per square inch.	7
Between 15,000 and 20,000 lbs.	16
Between 20,000 and 25,000 lbs.	30
Between 25,000 and 30,000 lbs.	12
Over 30,000 lbs. per square inch.	10
Total tests	<hr/> 75

From this grouping it can be inferred that the average granite will fall within the third class of the above table. As a matter of fact, the arithmetical average of all of the seventy-five tests recorded in Table 27 is actually 23,228 pounds per square inch.

* The low results are on schists and poor gneisses; the highest results are the remarkable tests reported by the Wisconsin Geological Survey.

TABLE 27.—COMPRESSIVE STRENGTH OF AMERICAN GRANITES.

						No. spec.	Size of cube.	Post.	First crack.	Ultimate strength.
							In.			
Arkansas	Fourche Mt., Pulaski Co.	Rensselaer Poly. Inst.	2.63				In.			
	Braddock quarry. Fourche Mt., Pulaski Co.	Watertown Arsenal	2.69			7	4			17,407 21,562 27,518
California	Rocklin Granite Co., Rocklin, Placer Co.	Watertown Arsenal				3	4			19,809 21,104 21,817
Connecticut	Booth Bros., Waterford, New London Co.	I. H. Woolson, Columbia Univ.				2	2			23,510 23,715 23,921
	Columbia Granite Co., Middletown, Middlesex Co.	I. H. Woolson, Columbia Univ.				12	2			29,400 31,660 34,075
	Columbia Granite Co., Middletown, Middlesex Co.	I. H. Woolson, Columbia Univ.				16	2			20,470 22,660 25,450
	Leete's Island.		2.649							
	Stony Point.		2.638							
Delaware	Stewart & Donohue, Augustine, Newcastle Co.	Booth, Garrett and Blair	2.77			2	2			24,750 24,913 25,075
Georgia	Venable Bros., Stone Mountain Venable Bros., Lithonia.	Watertown Arsenal				2	?			25,630 26,380 28,130
	Maheer quarry, Stockbridge, Henry Co.	Watertown Arsenal				3	?			28,250 28,953 30,320
Maine	Freeport, Cumberland Co.	Watertown Arsenal				4	2			22,657 25,910 31,213
	Booth Bros., Hurricane Isle, Knox Co.	Ira H. Woolson, Columbia Univ.	2.627							
	Booth Bros., Jonesboro, Washington Co.	Ira H. Woolson, Columbia Univ.				2	2		18,000	19,583
	Booth Bros., Waldoboro, Lincoln Co.	Ira H. Woolson, Columbia Univ.				2	2		21,225	24,507
	Maine and N. H. Granite Co., North Jay, Franklin Co.	Watertown Arsenal				2	2			23,111
	Maine and N. H. Granite Co., North Jay, Franklin Co.	Watertown Arsenal	2.639			3	3			22,367
	Chase Granite Co., Blue Hill, Hancock Co.	Watertown Arsenal				6	6			16,310
	Hancock Co.	Ricketts & Banks				2	2			23,425
	Mt. Waldo Granite Works, Frankfort, Waldo Co.	Watertown Arsenal				4	2			29,183 30,949 32,635
	Treat and Son, Millbridge, Washington Co.	Watertown Arsenal				10	1			22,560 24,602 26,770
	White Granite Co., Blue Hill.	Watertown Arsenal								23,420
	Deer Isle, Hancock Co.	Col. School of Mines				3				29,681
	High Isle, Knox Co.	Pittsburg Test Lab				3				16,610 18,890 22,530
		Col. School of Mines	2.641 165.1			4	2			25,880 30,955 33,665

TABLE 27. — COMPRESSIVE STRENGTH OF AMERICAN GRANITES (Continued).

						No. spec.	Size, cube, in.	Post.	First crack.	Ultimate strength.
Maine Massachusetts	Clark Island, Knox Co.....	Pittsburg Test Lab...				2	In.	.....	.....	13,000 14,000 15,175
	Cutting Granite Co., Milford, Worcester Co.....	Watertown Arsenal...				2	4	.....	.....	22,252 24,739 27,226
	Rockport Granite Co., Cape Ann, Essex Co.....	Watertown Arsenal...	2,618			1	*	.....	.....	20,206
	Shea Pink Granite Co., Milford, Worcester Co.....	Watertown Arsenal...				4	4	.....	.....	30,888
	Milford Granite Contr. Co., Milford, Worcester Co.....	Watertown Arsenal...				6	4	.....	.....	20,000
Missouri	Milford Granite Contr. Co., Milford, Worcester Co.....	Watertown Arsenal...				5	2	.....	.....	17,400 22,940 29,200
	Milford Granite Co., Milford, Worcester Co.....	Watertown Arsenal...				2	6	.....	.....	22,600 22,605 22,610
	Norcross Bros. Co., Milford, Worcester Co.....	Watertown Arsenal...				6	6	.....	.....	20,883
	Quincy	H. S. Washington	2,642					.....	.....	.....
	Syenite, Iron Co.....	Missouri Geol. Survey				7	5	.....	.....	18,236 23,703
New Hampshire	Syenite, Iron Co.....	Missouri Geol. Survey				11	5	.....	.....	22,883 31,550
	Graniteville, Iron Co.....	J. B. Johnson, St Louis				2	4	.....	.....	24,747 25,317
	Graniteville, Iron Co.....	Missouri Geol. Survey				10	5	.....	.....	19,410 23,726
	Webb Granite Co., Marlboro, Cheshire Co.....	Watertown Arsenal...				4	6	.....	.....	19,590 19,990 20,520
	Young & Sons, Milford, Hillsboro Co.....	Rensselaer Poly. Inst.						.....	.....	24,980
New York	Troy White Granite Co., Troy, Cheshire Co.....	Watertown Arsenal...				1	6	.....	.....	17,950
	Concord, Merrimac Co.....	Watertown Arsenal...	2,65					.....	.....	23,860 27,345 30,880
	Redstone, Carroll Co.....		2,634					.....	.....	.....
	Hudson Power Co., Hadley, Saratoga Co.....	Pittsburg Testing Laboratory.....				2		.....	.....	15,010 16,195 17,380
	Pochuch Quarry Co., Pochuch Mt., Orange Co.....	J. P. Carlin, Cornell Univ.				2	2	.....	.....	22,900 23,200 23,500
Pennsylvania	French Creek, Chester Co.....	R. L. Humphrey				3	8	.....	.....	16,144 17,274 18,404
	French Creek, Chester Co.....	R. L. Humphrey				3	2	.....	.....	19,832 19,997 20,165
	Holmesburg Granite Co., Holmesburg, Phila. Co.....	Lathbury & Spachman				2	2 1/2	.....	.....	15,024 20,606 26,284
	Germantown, Phila. Co.....	R. L. Humphrey				2	8	.....	.....	9,657 11,636 13,614
	Germantown, Phila. Co.....	R. L. Humphrey				3	2	.....	.....	14,459 19,891 23,416

TABLE 27.—COMPRESSIVE STRENGTH OF AMERICAN GRANITES (Concluded).

						No. spec.	Size of cube, in.	Position.	First crack.	Ultimate strength.
Pennsylvania	Conshohocken, Montgomery Co.	R. L. Humphrey	2.671	0.127	6	2	2	.....	.....	7,844 10,417 14,331
	Conshohocken, Montgomery Co.	R. L. Humphrey	2.654	.....	3	2	2	.....	.....	16,285 20,038 22,593
South Carolina	Keystone Granite Co., Paconlet, Spartanburg Co.	Pittsburg Testing Lab.	.....	.....	.....	.....	.....	.....	.....	21,420
	Westerly	Watertown Arsenal	.....	.....	.....	.....	.....	.....	.....	31,970
Rhode Island	Westerly	Watertown Arsenal	.....	.....	.....	.....	.....	.....	.....	39,750
	Westerly	Watertown Arsenal	.....	.....	.....	.....	.....	.....	.....	28,540
Vermont	Wells, Lawson & Co., Barre, Washington Co.	W. C. Day, Swarthmore College, New C. S. McKenna, New York City	2.667	.....	6	2	2	.....	.....	14,968 17,182 19,957
	Ellis Granite Co., Bethel, Windsor Co.	Watertown Arsenal	.....	.....	3	2	2	.....	.....	23,300 23,350 23,400
Virginia	Woodbury, Washington Co.	Watertown Arsenal	.....	.....	3	2	2	.....	.....	19,850 20,806 22,460
	Black Mt., Windham Co.	Watertown Arsenal	.....	.....	1	2	2	.....	.....	27,810
Washington	Bethel, Windsor Co.	Watertown Arsenal	.....	.....	3	2	2	.....	.....	31,990 33,153 34,350
	Petersburg Granite Co., Petersburg, Dinwiddie Co.	Pittsburg Testing Lab.	.....	.....	1	2	2	.....	.....	25,100
Wisconsin	Richmond Granite Co., Richmond, Henrico Co.	Watertown Arsenal	.....	.....	2	2	2	.....	.....	25,520 27,072 28,625
	Moore & Sons, Snake River Soderberg quarry, Index	Purdue University	2.677	.....	3	2	2	.....	.....	10,730 14,263 16,400
Wisconsin	Washington Cut Stone Co., Little Spokane River	Purdue University	2.743	.....	3	2	2	.....	.....	13,900 15,080 16,610
	Amberg Granite Co., Athelstane Berlin Granite Co., Berlin	Wisconsin University	2.679	.....	2	2	2	.....	.....	12,870 14,335 15,800
Wisconsin	Nelson Granite Co., Berlin	Wisconsin University	.....	.....	4	2	2	.....	.....	15,163 19,989 23,347
	French Granite Co., High Bridge	Wisconsin University	.....	.....	1	2	2	.....	.....	24,800
Wisconsin	Granite Hts. Co., Granite Hts.	Wisconsin University	.....	.....	3	2	2	.....	.....	44,009 45,891 47,674
	Leak's quarry, Irma	Wisconsin University	.....	.....	3	2	2	.....	.....	25,680 29,909 32,747
Wisconsin	Leuthold quarry, Granite City	Wisconsin University	.....	.....	1	2	2	.....	.....	24,229
	Cohn Granite Co., Granite Hts.	Wisconsin University	.....	.....	2	2	2	.....	.....	22,060 22,507 22,954
Wisconsin	Milwaukee Min. Co., Berlin	Wisconsin University	.....	.....	3	2	2	.....	.....	12,704 18,023 22,690
	Montello Granite Co., Montello	Wisconsin University	.....	.....	1	2	2	.....	.....	15,009 20,684 26,520
Wisconsin	O'Fair quarry, Granite Hts.	Wisconsin University	.....	.....	4	2	2	.....	.....	15,009 20,684 26,520
	Pike River Granite Co., Amberg	Wisconsin University	.....	.....	3	2	2	.....	.....	31,326 34,640 38,063
Wisconsin	Pike River Granite Co., Amberg	Wisconsin University	.....	.....	3	2	2	.....	.....	27,132 38,248 43,973
	Pike River Granite Co., Amberg	Wisconsin University	.....	.....	1	2	2	.....	.....	27,262
Wisconsin	Pike River Granite Co., Amberg	Wisconsin University	.....	.....	2	2	2	.....	.....	18,237 23,062 27,887

TABLE 28.—TRANSVERSE STRENGTH OF GRANITES.

State.	Locality.	Tested by	No. of tests.	Length.	Breadth.	Depth.	Minimum.	Average.	Maximum.
Arkansas.....	.....	Watertown	5	In. 20	In. 4	In. 6	1067	1400	1755
California.....	Exeter....	Watertown	....	20	4	6	....	1853	....
Georgia.....	Stone Mt..	Watertown	....	20	6	6	....	2610	....
Maine.....	Millbridge.	Watertown	2	20	4	6	2027	2048	2069
Massachusetts.	Cape Ann..	Watertown	....	19	4	6	....	2392	....
Wisconsin.....	Montello ..	Buckley...	2	4	1	1	3678	3794	3910
".....	New Hill..	Buckley...	2	4	1	1	2324	2519	2713

TABLE 29.—PHYSICAL PROPERTIES OF ENGLISH GRANITES (BEARE).

	Specific gravity.	Weight.	Absorb.	
Penrhyn.....	2.65	165.4	0.12	16,490
Cornwall.....	2.59	161.7	....	14,870
Aberdeenshire:				
Corennie.....	2.58	161.0	0.40	19,855
Cove.....	2.71	169.1	0.55	15,355
Kemnay.....	2.605	162.5	0.32	17,880
Craigton.....	....	....	....	19,935
Peterhead.....	2.54	158.5	0.29	18,785
Dyce.....	2.65	165.4	0.19	17,200
Hill of Fare.....	2.55	159.1	0.40	21,160
Sclattie.....	2.58	161.0	0.10	13,230
Persley.....	2.60	162.3	0.19	14,665
Rubislaw.....	2.623	163.7	0.09	18,575
Ben Cruachan.....	2.75	171.6	0.29	13,640

Geological Distribution of Granites. — Rocks of granitic type may have formed the greater proportion of the original crust of the earth, but it is improbable that any of these first-formed granites are now exposed at the surface. Granites and granitic gneisses, however, undoubtedly still make up the major portion of the pre-Cambrian rocks, so far as these rocks are now open to inspection. And in all of the geologic periods, from the pre-Cambrian to the Tertiary, masses of granite and allied rocks have been intruded into the existing formations. The result of this history is that, among the granites exposed at the surface to-day, almost every geologic age is represented in some part

of the world. When looked at in this broad fashion, little definite can be said regarding the geologic age of granites; but when the inquiry is limited to smaller areas the question of age admits of discussion.

The area which supplies by far the bulk of American commercial granites, for example, is that located in New England. The southward extension of the same area along the Blue Ridge and Appalachian regions promises to become of greater industrial importance yearly. In both of these areas, a relatively small portion of the granites and gneisses quarried are of pre-Cambrian age. The bulk of the commercial granites is derived from masses intruded into pre-Cambrian or later rocks during the Silurian, Devonian and Carboniferous periods; and it seems probable that most of these intrusive granites date back only to the Carboniferous.

In the western states a greater range in geologic age is shown, and here no general statement of value can be made, owing to the relatively small development of the granite industry.

Granites do *not* occur in Ohio, West Virginia, Tennessee, Indiana, Illinois, Florida, Mississippi, Louisiana, Kansas, Iowa, Nebraska and North Dakota; they occur at only one or two localities in South Dakota and Kentucky; and in small areas only in Missouri, Arkansas, Texas and Oklahoma. In the remaining states rocks of granitic type cover considerable areas.

Production of Granite in the United States. — The following tables, revised slightly from those published by the United States Geological Survey, give statistics concerning the granite industry for a series of years. It is to be noted, however, that in these tables trap and other basic igneous rocks are included under the general head of "granite" in most states.

TABLE 30. — GRANITE PRODUCTION OF THE UNITED STATES, 1899–1909.

Year.	Value.	Year.	Value.
1899	\$10,343,298	1905	\$17,563,139
1900	10,969,417	1906	18,562,806
1901	14,266,104	1907	18,064,708
1902	16,083,475	1908	18,420,080
1903	15,703,793	1909	19,581,597
1904	17,191,479	1910	20,541,967

TABLE 31. — GRANITE PRODUCTION, BY STATES, 1905-1909.

State or Territory.	1905.	1906.	1907.	1908.	1909.
Arizona.....	\$3,700	\$32,042	\$13,700	\$8,544	(^a)
Arkansas.....	90,312	118,903	168,996	152,567	\$150,179
California.....	1,161,330	740,784	1,306,324	1,684,504	1,310,520
Colorado.....	73,802	65,402	67,134	121,282	74,326
Connecticut.....	636,364	974,024	591,153	592,904	610,514
Delaware.....	178,428	146,346	158,192	195,761	456,328
Georgia.....	971,207	792,315	858,603	970,832	843,542
Hawaii.....	33,550	23,346	19,599	81,219	68,955
Idaho.....	1,500	400	25,942	(^a)	(^a)
Maine.....	2,713,795	2,560,021	2,146,420	2,027,508	1,939,524
Maryland.....	957,048	883,881	1,183,753	762,442	771,224
Massachusetts.....	2,251,319	3,327,416	2,328,777	2,027,463	2,164,619
Michigan.....					} ^b 660,823
Minnesota.....	481,908	626,069	546,603	629,427	
Missouri.....	180,579	150,009	136,405	157,968	155,717
Montana.....	126,430	114,005	102,050	(^a)	(^a)
Nevada.....					
New Hampshire....	838,371	818,131	647,721	867,028	1,215,461
New Jersey.....	76,758	101,224	75,757	125,804	60,175
New Mexico.....			167,294		(^a)
New York.....	134,425	304,048	289,722	367,066	443,910
North Carolina....	564,578	778,847	889,976	764,272	743,876
Oklahoma.....	20,720	18,847	24,550	23,239	67,584
Oregon.....	85,330	58,961	117,625	271,869	284,135
Pennsylvania.....	450,619	349,453	366,679	324,241	507,814
Rhode Island.....	556,364	622,812	674,148	556,474	933,053
South Carolina.....	297,284	247,998	129,377	297,874	218,045
South Dakota.....			690	(^a)	
Texas.....	132,193	168,061	122,158	190,055	173,271
Utah.....	13,630	4,948	5,240	5,229	7,525
Vermont.....	2,571,850	2,934,825	2,693,889	2,451,933	2,811,744
Virginia.....	452,390	340,900	398,426	321,530	488,250
Washington.....	681,730	459,975	562,352	870,944	742,878
Wisconsin.....	825,625	798,213	1,228,863	1,529,781	1,442,305
Wyoming.....		600	90	(^a)	
Other States.....				40,320	^c 235,300
Total.....	17,563,139	18,562,806	18,064,708	18,420,080	19,581,597

^a Included in "Other States."^b Includes a small value for trap rock in Michigan and Minnesota.^c Includes Arizona, Idaho, Montana, and New Mexico.

TABLE 32. — GRANITE PRODUCTION OF 1909, BY STATES AND USES.

State or Territory.	Sold in the rough.					Dressed for building.	Dressed for monumental work.	Made into paving blocks.
	Building.	Monu- mental.	Rubble.	Riprap.	Other.			
Arkansas.....	\$1,000		\$9,522	\$68,000		\$799	\$120	
California.....	30,536	\$39,579	12,798	109,847	\$2,875	432,551	97,978	\$34,470
Colorado.....	15,267	28,451	4,950	18	1,200	24,000		
Connecticut.....	25,097	35,867	5,342	112,830	1,382	274,501	66,538	8,698
Delaware.....	9,769		1,557	280,488		2,043		9,084
Georgia.....	39,685	28,174	33,216	59,245		120,270	2,693	93,300
Hawaii.....	3,100							
Maine.....	237,597	31,375	14,685	14,090	26,271	1,152,677	39,704	262,895
Maryland.....	120,561	8,471	70,479	6,695	4,450	114,002	2,675	93,742
Massachusetts.....	212,075	508,805	51,658	2,462	17,752	542,441	298,235	308,203
Minnesota.....	43,659	76,636	48,210	1,093		144,997	167,088	66,605
Missouri.....	4,093	46,750		3,878		5,930	2,300	46,163
New Hampshire.....	143,757	70,018	23,387	4,367	200	521,299	192,762	170,434
New Jersey.....	7,366	1,000	150	200	942	1,133	50	2,250
New York.....	35,399	1,864	17,639	5,421	2,971	17,193	23,903	250,070
North Carolina.....	56,859	11,682	5,803	34		142,778	38,192	214,508
Oklahoma.....	1,471	16,541	13,050	8,000		15,408	5,691	
Oregon.....	6,996	5,460				2,321	16,129	37,348
Pennsylvania.....	306,466	10,400	4,751		1,950	53,529		15,840
Rhode Island.....	45,501	178,565	1,510		73	218,089	314,237	52,004
South Carolina.....	67,877	5,215	19,680	53,037	1,755	1,000		4,284
Texas.....	29,530	36,082		22,141	2,875	36,612	11,400	
Utah.....	996	4,396					2,133	
Vermont.....	128,233	1,154,826	1,037	4,100	100	1,035,075	479,415	5,824
Virginia.....	24,965	1,966	33,321	1,386		17,750	9,449	18,053
Washington.....	11,478	6,308	423,230	18,408		17,185	19,902	66,544
Wisconsin.....	300	26,984	420			5,154	212,043	982,798
Other States.....	2,502	8,940	1,000			22,000	3,000	
Total.....	1,612,135	2,342,355	797,395	775,740	64,796	4,920,737	2,005,637	2,743,117

TABLE 32.—GRANITE PRODUCTION OF 1909, BY STATES AND USES. (*Concluded.*)

State or Territory.	Curbing.	Flagging.	Crushed stone.			Other.	Total.
			Road-making.	Railroad ballast.	Concrete.		
Arizona.....							(a)
Arkansas.....	\$300		\$68,338	\$1,470	\$630		\$150,179
California.....	163,012	\$375	262,077	57,064	65,020	\$2,338	1,310,520
Colorado.....						440	74,326
Connecticut.....	45,573	250	7,834		23,752	2,850	610,514
Delaware.....	3,960		20,105	98,485	30,337	500	456,328
Georgia.....	318,957	240	16,405	46,864	83,497	996	843,542
Hawaii.....			40,855		25,000		68,955
Idaho.....							(a)
Maine.....	74,739	13,770	10,786	330	7,849	52,756	1,939,524
Maryland.....	3,474	2,427	138,465	38,576	158,468	8,739	771,224
Massachusetts.....	113,705	3,666	56,805	8,533	36,344	3,935	2,164,619
Michigan.....							(b)
Minnesota.....	8,154	150	40,221	26,220	36,540	1,250	c 660,823
Missouri.....			15,345		31,258		155,717
Montana.....							(a)
New Hampshire.....	53,058	635	21,429		9,360	4,775	1,215,461
New Jersey.....				44,960	2,124		60,175
New Mexico.....							(a)
New York.....	1,352		52,263	2,600	33,235		443,910
North Carolina.....	98,153	1,233	44,617	28,151	101,866		743,876
Oklahoma.....	2,000				3,500	1,923	67,584
Oregon.....		3,004	206,372	1,025	5,480		284,135
Pennsylvania.....	8,401	3,490	41,047	5,625	39,004	17,311	507,814
Rhode Island.....	5,955		99,358	2,617	17,125	19	933,053
South Carolina.....	3,554	125	10,672	15,827	32,834	2,185	218,045
Texas.....	1,100		32,584		947		173,271
Utah.....							7,525
Vermont.....	1,319		765	1,000		50	2,811,744
Virginia.....	29,100	990	74,054	125,704	147,112	4,400	488,250
Washington.....	76,574		88,868			14,381	742,878
Wisconsin.....	3,048	16,875	125,838		23,385	45,460	1,442,305
Other States (a).....	15,100		13,608	155,581		13,569	235,300
Total.....	1,030,568	47,230	1,488,711	660,632	914,667	177,877	19,581,597

a Included in "Other States."

b A small value for trap rock included in Minnesota.

c Includes a value of trap rock for Michigan and Minnesota.

d "Other States" includes Arizona, Idaho, Montana, and New Mexico.

TABLE 33.—NUMBER AND VALUE OF GRANITE PAVING BLOCKS PRODUCED IN 1908 AND 1909, BY STATES AND TERRITORIES.

State or Territory.	Paving blocks.			
	1908.		1909.	
	Number.	Value.	Number.	Value.
California.....	1,657,600	\$66,079	817,500	\$34,470
Connecticut.....	292,485	14,951	180,130	8,698
Delaware.....	121,000	6,050	187,095	9,084
Georgia.....	4,735,770	135,510	3,384,600	93,300
Maine.....	8,005,662	368,715	6,137,682	262,895
Maryland.....	692,538	71,316	1,107,149	93,742
Massachusetts.....	6,134,648	261,880	6,878,872	308,203
Minnesota.....	532,750	35,750	974,000	66,605
Missouri.....	1,826,742	75,320	1,150,914	46,163
New Hampshire.....	2,842,206	103,833	4,997,161	170,434
New Jersey.....	96,956	2,674	30,000	2,250
New York.....	1,573,777	98,273	3,571,997	250,070
North Carolina.....	3,679,745	122,488	5,062,500	214,508
Oklahoma.....	5,900	400	.....	.....
Oregon.....	1,000,000	40,000	936,260	37,348
Pennsylvania.....	529,037	23,628	374,171	15,840
Rhode Island.....	567,416	29,651	1,051,681	52,004
South Carolina.....	351,250	12,277	106,204	4,284
Texas.....	6,000	300	.....	.....
Vermont.....	58,200	1,547	163,885	5,824
Virginia.....	358,664	10,173	853,300	18,053
Washington.....	3,000	255	1,109,072	66,544
Wisconsin.....	13,399,882	939,485	18,798,977	982,798
Total.....	48,471,228	2,420,555	57,873,150	2,743,117
Average price per thousand.....	.....	49.94	.....	47.40

TABLE 34. — PRODUCTION OF GRANITE IN VERMONT IN
1908 AND 1909, BY COUNTIES AND USES.
1908.

County.	Number of firms re- porting.	Building.			
		Rough.		Dressed.	
		Quantity (cubic feet).	Value.	Quantity (cubic feet).	Value.
Washington and Orange.....	39	15,896	\$9,871	129,230	\$429,967
Windsor.....	3	63,537	59,054	52,866	244,850
Caledonia and Orleans.....	9	12,753	3,999	.....	.....
Windham.....	3	12,050	6,787	1,225	1,250
Total.....	54	104,236	79,711	173,321	676,067
Average price per cu. ft.....	.....	.....	.76	.....	3.90

County.	Monumental.				Paving.		Other purposes.	Total value.
	Rough.		Dressed.		Quantity (number of blocks).	Value.	Value.	
	Quantity (cubic feet).	Value.	Quantity (cubic feet).	Value.				
Washington and Orange	1,094,619	\$1,015,006	164,706	\$576,551	50,400	\$1,262	\$14,443	\$2,047,100
Windsor	12,000	6,000						309,904
Caledonia and Orleans	117,560	66,580	1,000	5,000			2,175	77,754
Windham	11,750	7,637	200	500	7,800	285	716	17,175
Total	1,235,929	1,095,223	165,906	582,051	58,200	1,547	17,334	2,451,933
Average price per cu. ft. ....		.89		3.51				

TABLE 34.—PRODUCTION OF GRANITE IN VERMONT IN
1908 AND 1909, BY COUNTIES AND USES (*Concluded*).
1909.

County.	Number of firms re- porting.	Building.			
		Rough.		Dressed.	
		Quantity (cubic feet).	Value.	Quantity (cubic feet).	Value.
Washington and Orange.....	34	44,020	\$17,457	381,730	\$1,034,575
Windsor.....	3	111,020	88,816		
Caledonia and Essex.....	10	45,000	17,285		
Windham.....	3	12,950	4,550		
Orleans.....	3	750	125	.....	.....
Total.....	53	213,740	128,233	382,230	1,035,075
Average price per cu. ft.....	.....	.....	.60	.....	2.71

County.	Monumental.				Paving.		Other purposes.	Total value.
	Rough.		Dressed.		Quantity (number of blocks)	Value.	Value.	
	Quantity (cubic feet).	Value.	Quantity (cubic feet).	Value.				
Washington and Orange } Windsor Caledonia and Essex..... Windham..... Orleans.....	1,210,696 94,962 233 37,943	\$1,094,616 44,789 233 15,188	173,242 100 400	\$478,349 250 816	29,885 134,000	\$897 4,927	\$8,161 { 110 100	\$2,297,910 424,961 62,574 10,070 16,229
Total..... Average price per cu. ft....	1,343,834	1,154,826 .86	173,742	479,415 2.76	163,885	5,824	8,371	2,811,744

References on Granites.— The following list contains the principal papers and reports dealing with granites and allied stones, chiefly from a commercial standpoint. For convenience of reference, the titles are arranged by states, in alphabetical order.

Alabama:

Watson, T. L. Granites of the southeastern Atlantic States. Bull. 426, U. S. Geol. Sur., 1910. Alabama granites on pp. 268, 269.

Arkansas:

Williams, J. F. The igneous rocks of Arkansas. Vol. II, Ann. Rep. Ark. Geol. Sur. for 1890, 457 pp. 1891.

California:

Anon. Granites of California. Bull. 38, Calif. State Mining Bureau, pp. 23-61. 1906.

Connecticut:

Dale, T. N. Granites of Connecticut. Bull. . . . , U. S. Geol. Sur. (in press, 1911).

Georgia:

Watson, T. L. Preliminary report on the granites of Georgia. Bull. 9, Georgia Geol. Sur., 367 pp. 1902.

Watson, T. L. Granites of the southeastern United States. Bull. 426, U. S. Geol. Sur., 1910. Georgia granites on pp. 206-267.

Maine:

Dale, T. N. The granites of Maine. Bull. 313, U. S. Geol. Sur., 202 pp. 1907.

Maryland:

Grimsley, G. P. The granites of Cecil County, in northeastern Maryland. Jour. Cinn. Soc. Nat. Hist., Vol. XVII, pp. 59-67, 78-114. 1894.

Keyes, C. R. The origin and relations of Central Maryland granites. 15th Ann. Rep. U. S. Geol. Sur., pp. 685-740. 1895.

Mathews, E. B. Granites and gneisses of Maryland. Vol. II, Rep. Md. Geol. Sur., pp. 136-169. 1898.

Watson, T. L. Granites of the southeastern United States. Bull. 426, U. S. Geol. Sur., 1910. Maryland granites on pp. 39-69.

Williams, G. H. Granitic rocks in the middle Atlantic piedmont plateau. 15th Ann. Rep. U. S. Geol. Sur., pp. 657-684. 1895.

Massachusetts:

Dale, T. N. The chief commercial granites of Massachusetts. Bull. 354, U. S. Geol. Sur., pp. 73-144. 1908.

Minnesota:

Winchell, N. H. The comparative strength of Minnesota and New England granites. 12th Ann. Rep. Minn. Geol. Sur., pp. 14-18. 1884.

Missouri:

Buehler, H. A. Granites and rhyolites of Missouri. Rep. Mo. Geol. Sur., 2d series, Vol. II, pp. 60-85. 1904.

New Hampshire:

Dale, T. N. The chief commercial granites of New Hampshire. Bull. 354, U. S. Geol. Sur., pp. 144-188. 1908.

New Jersey:

Lewis, J. V. Building stones of New Jersey. Ann. Rep. State Geologist N. J. for 1908. Granite, pp. 62-81. 1909.

New York:

Eckel, E. C. The quarry industry in southeastern New York. 20th Ann. Rep. N. Y. State Geologist, pp. 141-176. 1902.

Smock, J. C. Building stones in the State of New York. Bull. 3, N. Y. State Museum, 152 pp. 1888.

Smock, J. C. Building stone in New York. Bull. 10, N. Y. State Museum, 396 pp. 1890.

North Carolina:

Watson, T. L. Granites of the southeastern United States. Bull. 426, U. S. Geol. Sur., 1910. North Carolina, pp. 115-170.

Rhode Island:

Dale, T. N. The chief commercial granites of Rhode Island. Bull. 354, U. S. Geol. Sur., pp. 188-210. 1908.

South Carolina:

Watson, T. L. Granites of the southeastern United States. Bull. 426, U. S. Geol. Sur., 1910. South Carolina, pp. 172-205.

South Dakota:

Todd, J. E. The newly discovered rock at Sioux Falls, South Dakota. Am. Geologist, Vol. XXXIII, pp. 35-39. 1904.

Texas:

Burchard, E. F. Structural materials in the vicinity of Austin, Texas. Bull. 430, U. S. Geol. Sur., pp. 292-316.

Vermont:

Dale, T. N. The granites of Vermont. Bull. 404, U. S. Geol. Sur., 138 pp. 1909.

Finlay, G. I. The granite area of Barre, Vermont. Rep. Vt. State Geologist for 1901-1902, pp. 46-59. 1902.

Perkins, G. H. Report on the marble, slate, and granite industries of Vermont, 68 pp. Rutland, 1898.

Perkins, G. H. Granite (in Vermont). Rep. Vt. State Geologist for 1899-1900, pp. 57-77. 1900.

Virginia:

Watson, T. L. Granites of the southeastern United States. Bull. 426, U. S. Geol. Sur., 1910. Virginia, pp. 70-115.

Washington:

Landes, H. The building and ornamental stones of Washington. Vol. II. Rep. Wash. Geol. Sur., 1903. Granites, pp. 32-47.

Wisconsin:

Buckley, E. R. Building and ornamental stones of Wisconsin. Bull. 4, Wis. Geol. Sur., 500 pp. 1898.

CHAPTER IV.

TRAP ROCK AND OTHER BASIC IGNEOUS STONES.

Scope of Term. — The term **trap rock** is applied commercially to a series of basic igneous rocks which usually agree in being dark-colored, dense and fine-grained. With few exceptions, the commercial trap rocks are geologically classified as either basalt, diabase or gabbro. Occasionally, however, some of the finer-grained, dark-colored diorites are marketed as trap.

For convenience, so as to avoid too violent a separation of geologically allied rocks, all of the more basic rocks will be treated together in the present chapter. The groups thus covered include the diorites, gabbros, diabase and basalt, and the still more basic peridotites, pyroxenites and hornblendites.

Occurrence of Trap Rocks. — The general modes of occurrence of igneous rocks have been discussed on pages 17–20 of this volume, but in the present place it will be well to consider, in somewhat greater detail, such phases of this matter as bear on the occurrence of trap rocks in particular.

For our present purpose it is sufficiently exact to say that practically all of the basic igneous rocks which are of commercial importance will be found to occur in one of the following types of deposit:

(1) In certain regions of pre-Cambrian rocks, both massive basic rocks and basic gneisses are found to cover considerable areas. Most of the traps of Wisconsin, Minnesota and Michigan are of this type; while many of the basic gneisses quarried in the eastern states are also from pre-Cambrian areas.

(2) The bulk of the commercial trap rock, however, comes from deposits which are of more recent and more clearly recognizable origin. In Massachusetts, Connecticut, New York, New Jersey, Pennsylvania and Virginia the trap quarried is of Triassic age, and comes from intrusive sheets or surface flows. More rarely quarries of trap are established on dikes or in old volcanic necks.

Color. — Owing to their low silica content, and the prevalence of iron minerals, the basic igneous rocks are commonly dark colored. In the coarser-grained varieties of gabbro and diorite, the color effect may be mottled, the dark iron minerals being set off by feldspars which are lighter in tint, though in the basic rocks even the feldspars are commonly bluish or grayish. In the finer-grained diorites and gabbros, and in the basalts, diabases and ultrabasic rocks the color is commonly almost uniform, and ranges from dark green or dark gray to almost black.



Fig. 16. — Columnar structure of trap. (Photo by N. H. Darton.)

The above notes apply to the colors shown by these rocks when fresh. As all the basic rocks are susceptible to weathering, old outcrops usually show very different colors from that of the fresh rock. On such weathered surfaces any feldspar which the rock may contain is usually a dull chalky white; while the iron-bearing minerals have taken on yellowish, reddish or brown tints.

Mineral Constitution. — In none of the basic igneous rocks is quartz an important constituent; and in most of them it is either entirely or practically lacking. The feldspar of the basic rocks is usually plagioclase, and not orthoclase. When a mica is

present, it is commonly biotite, and not muscovite. All of the basic rocks contain either hornblende, pyroxene or olivine; and in some cases very large amounts of one or more of these very basic minerals.

The proportions of the various minerals present in a number of specimens of diabase from New Jersey has been determined by Lewis with the results shown in the following table. For convenience of comparison, Lewis' results have been renumbered, so as to correspond with the numbers given to the chemical analyses of the same specimens in Table 38 on a later page.

TABLE 35. — MINERAL PROPORTIONS IN TRAP ROCKS.

	1	2	6	7	8	9	10
	Per cent	Per cent					
Quartz.....	19	7	0	0	0	0	0
Feldspar.....	44	42	20	38	37	30	26
Augite.....	27	34	73	46	59	63	56
Biotite.....	3	0	1	1	0	0	1
Olivine.....	0	0	4	13	1	5	16
Magnetite, etc.....	7	17	2	2	3	2	1

Identification of Constituents. — Except in dealing with very coarse-grained types it will rarely be possible to identify the mineral constituents of a basic rock by merely examining it with the naked eye or even with a hand lens. In order to classify the rock correctly, either chemical analysis or microscopic investigation will be necessary, and frequently both will be required.

Chemical Composition. — The rocks included in this group are all characteristically low in silica, and relatively high in iron oxide, magnesia, lime and alkalies.

The following tables (Tables 36-40) contain analyses of a representative series of commercial trap rocks from various producing localities in the United States. With these have been included a few analyses of basic rocks from localities which have not yet entered the producing list, but which may reasonably be expected to do so in the near future.

TABLE 36. — ANALYSES OF TRAP: CONNECTICUT.

	1	2	3	4
Silica (SiO ₂).....	52.37	50.26	49.27	49.29
Alumina (Al ₂ O ₃).....	15.06	15.16	15.87	15.97
Titanic oxide (TiO ₂).....	0.21			
Ferric oxide (Fe ₂ O ₃).....	2.34 }	13.70	{ 1.93	1.88
Ferrous oxide (FeO).....	9.82 }		{ 10.17	10.23
Manganous oxide (MnO).....	0.32	0.48	0.35	0.40
Lime (CaO).....	7.33	10.68	7.46	7.42
Magnesia (MgO).....	5.38	5.49	5.90	6.07
Potash (K ₂ O).....	0.92	n.d.	0.71	0.69
Soda (Na ₂ O).....	4.04	n.d.	3.45	3.35
Carbon dioxide (CO ₂).....			1.12	1.17
Water above 100° C. }	2.24	4.23	3.92	3.88
Water below 100° C. }				

1. Connecticut Trap Rock Quarries Company, Meriden; J. H. Pratt, analyst; 18th Ann. Rep. U. S. Geol. Sur., pt. 5.
2. Cooke Trap Rock Company, Plainville; H. Souther, analyst; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 365.
- 3, 4. Tidewater Trap Rock Company, East Haven; G. W. Hawes, analyst; Min. Res. U. S. for 1903.

TABLE 37. — TRAP: MASSACHUSETTS AND MINNESOTA.

	1	2	3	4	5	6
Silica.....	52.59	46.11	50.43	35.83	48.32	48.51
Alumina.....	23.42	17.20	23.83		35.95	13.79
Ferric oxide.....	14.55	12.07	17.63	48.45	..... }	19.34
Ferrous oxide.....		4.87				
Lime.....	9.05	10.96	4.79	9.35	12.05	8.34
Magnesia.....	0.28	4.24	2.46	3.12	0.25	4.81
Potash.....			0.34	0.22	0.19	0.19
Soda.....			2.06	1.66	2.98	1.67
Water.....		3.06				

1. Monson, Hampden County, Mass.; Watertown Arsenal, analysts; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 405.
2. West Roxbury, Suffolk County, Mass.; H. P. Williams, analyst; Min. Res. U. S. for 1903, pamphlet ed., p. 119.
3. Duluth, St. Louis County, Minn. Dodge. Vol. I, Rep. Minn. Geol. Sur., p. 198.
4. Taylor's Falls, Chicago County, Minn. Dodge. Vol. I, Rep. Minn. Geol. Sur., p. 198.

5. Beaver Bay, Lake County, Minn. Dodge. Vol. I, Rep. Minn. Geol. Sur., p. 198.
 6. Tischer's Creek, St. Louis County, Minn. Dodge. Vol. I, Rep. Minn. Geol. Sur., p. 198.

TABLE 38. — ANALYSES OF TRAP ROCKS: NEW JERSEY.*

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO ₂ ..	60.05	51.34	53.13	51.88	50.40	52.48	49.62	51.14	51.03	49.02	46.78	51.46	50.34
Al ₂ O ₃ ..	11.88	12.71	13.75	14.53	15.60	14.98	10.51	12.99	11.92	10.14	14.33	13.98	15.23
Fe ₂ O ₃ ..	3.22	2.65	1.07	1.35	3.65	1.13	0.64	1.50	1.52	1.54	5.76	2.66	2.82
FeO ..	10.21	14.14	9.10	9.14	6.30	9.25	12.02	9.14	10.85	10.46	9.27	8.92	11.17
MgO ..	0.85	3.66	8.57	7.78	6.08	7.75	15.98	11.58	12.08	17.25	1.58	7.59	5.81
CaO ..	4.76	7.44	9.47	9.98	10.41	10.83	7.86	10.08	9.22	8.29	5.26	10.49	9.61
Na ₂ O ..	4.04	2.43	2.30	2.06	2.57	1.87	1.40	1.72	1.50	1.59	3.43	4.75	2.93
K ₂ O ..	2.10	1.44	1.04	0.93	0.62	0.43	0.55	0.52	0.39	0.40	1.75	1.02	0.07
H ₂ O+	0.66	0.69	0.90	0.97	1.67	0.23	0.49	0.59	0.54	0.59	0.10	0.07	0.19
H ₂ O-	0.21	0.18	0.90	0.12	1.02	0.18	0.38	0.14	0.17	0.16	0.33	1.06	1.56
TiO ₂ ..	1.74	3.47	.....	1.35	1.35	1.30	1.01	1.13	0.93	0.99	1.44	0.17	0.20
P ₂ O ₅ ..	0.52	0.20	.....	0.14	0.16	0.13	0.16	0.06	0.08	0.11	0.36	0.17	0.20
MnO ..	0.28	0.36	0.44	0.10	0.06	0.27	0.09	0.16	0.15	0.16	0.25	.....	0.14
	100.52	100.71	99.77	100.33	99.89	100.83	100.71	100.75	100.38	100.70	100.64	101.08	101.09
Sp. gr.	2.872	3.089	2.96	2.98	2.89	3.110	3.118	3.051	3.122	3.152	.....	.....	2.968

	14	15	16	17	18	19	20	21	22
SiO ₂	50.19	51.09	51.77	51.82	51.84	51.36	49.68	49.17	49.71
Al ₂ O ₃	14.65	14.23	14.59	14.18	15.11	16.25	14.02	13.80	13.66
Fe ₂ O ₃	3.41	2.56	3.62	0.57	1.78	2.14	4.97	4.90	5.49
FeO.....	6.96	7.74	6.90	9.07	8.31	8.24	9.52	10.61	9.51
MgO.....	7.95	7.56	7.18	8.39	7.27	7.97	5.80	5.04	6.13
CaO.....	9.33	10.35	7.79	8.60	10.47	10.27	-6.50	9.87	5.85
Na ₂ O.....	2.64	1.92	3.92	2.79	1.87	1.54	3.49	2.21	4.51
K ₂ O.....	0.75	0.42	0.64	1.26	0.34	1.06	1.41	0.54	0.37
H ₂ O+	2.38	1.01	1.85	1.40	1.33	1.33	1.89	0.73	2.66
H ₂ O-	0.66	1.66	0.46	0.30	0.56	.....	0.54	1.04	0.48
TiO ₂	1.13	1.30	1.13	1.17	1.22	.....	1.39	1.50	1.53
P ₂ O ₅	0.18	0.16	0.18	0.17	0.13	.....	0.21	0.24	0.10
MnO.....	0.07	0.25	0.05	0.13	0.09	0.09	0.18	0.07	0.13
	100.30	100.25	100.08	99.85	10.32	100.28	99.60	99.75	100.13
Sp. gr.....	2.92	2.936	2.91	2.95	2.93	.....	2.949	2.997	2.91

* Ann. Rep. N. J. State Geol. for 1907, pp. 120 et seq. contain analyses 1-22 of this table.

1. Quartz diabase, Penn. R. R. tunnel, Homestead; R. B. Gage, analyst.
2. Quartz diabase, Penn. R. R. cut, near Marion Station, Jersey City; R. B. Gage, analyst.
3. Diabase, Railroad cut, Jersey City; G. W. Hawes, analyst.
4. Diabase, Penn. R. R. tunnels, Weehawken; R. B. Gage, analyst.
5. Diabase, N. Y., Susquehanna & Western R. R. tunnel; R. B. Gage, analyst.
6. Diabase, road to West Shore Ferry, Weehawken; R. B. Gage, analyst.

7. Olivine diabase, second road to West Shore Ferry, Weehawken; R. B. Gage, analyst.
- 8, 9. Diabase, Englewood Cliffs; R. B. Gage, analyst.
10. Olivine diabase, Englewood Cliffs; R. B. Gage, analyst.
- 11, 12, 13. Diabase, quarry near Rocky Hill station; A. H. Phillips, analyst.
14. Hartshorn's quarry, near Springfield and Short Hills, lower "gray" layer; R. B. Gage, analyst.
15. Same locality, middle "black" layer; R. B. Gage, analyst.
16. Same locality, upper "gray" layer; R. B. Gage, analyst.
17. Hatfield & Weldon's quarry, Scotch Plains, lower "gray" layer; R. B. Gage, analyst.
18. Same locality, "black" rock above; R. B. Gage, analyst.
19. O'Rourke's quarry, West Orange. Large columns near the bottom. (Bull. U. S. Geol. Sur., No. 150, p. 255); L. G. Eakins, analyst.
20. Morris County Crushed Stone Co's. quarry, Millington, lower "gray" layer; R. B. Gage, analyst.
21. Same locality, middle "black" layer; R. B. Gage, analyst.
22. Same locality, upper "gray" layer; R. B. Gage, analyst.

The following table contains a number of less complete commercial analyses of trap rock from various localities in New Jersey.

TABLE 38A. — TRAP: NEW JERSEY.

	23	24	25	26	27
Silica.....	50.81	50.61	49.20	50.03	51.20
Alumina.....	13.25	18.34	14.50	18.20	20.88
Ferric oxide }	14.66	13.91	17.01	16.81	11.12
Ferrous oxide }					
Lime.....	10.96	7.01	7.50	11.10	12.50
Magnesia.....	6.97	6.73	6.30	1.02	2.17
Potash.....	1.71	1.08 }	1.69	1.03	1.03
Soda.....	0.76	1.60 }			
Water.....	0.88	1.72	3.80	1.81	1.10

23. Little Falls, Passaic County; W. C. Day, analyst; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 419.
24. Mine Brook, Somerset County; T. B. Stillman, analyst; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 419.
25. Millington, Morris County; T. B. Stillman, analyst; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 419.
26. Millington, Morris County; T. B. Stillman, analyst; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 419.
27. Millington, Morris County; T. B. Stillman, analyst; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 419.

TABLE 39. — ANALYSES OF GABBRO: NEW YORK.

	1	2
Silica (SiO_2).....	54.72	55.34
Alumina (Al_2O_3).....	17.79	16.37
Ferric oxide (Fe_2O_3).....	2.08	0.77
Ferrous oxide (FeO).....	6.03	7.54
Lime (CaO).....	6.84	7.51
Magnesia (MgO).....	5.85	5.05
Potash (K_2O).....	3.01	2.03
Soda (Na_2O).....	3.02	4.06
Water.....		0.58

1. Quaker Bridge, N. Y.; H. T. Vulte, analyst; "Handbook of Rocks," 3d ed., p. 72.
2. Montrose, N. Y.; Dunn, analyst; "Handbook of Rocks," 3d ed., p. 72.

TABLE 40. — ANALYSES OF TRAP ROCK: PENNSYLVANIA AND VIRGINIA.

	1	2	3	4	5	6	7
Silica.....	46.87	52.65	45.73	47.87	52.06	51.31	50.88
Alumina.....	13.36	17.02	13.48	14.43	13.67	13.64	13.17
Ferric oxide.....	9.79	4.61	11.60	11.55	15.97	0.52	1.11
Ferrous oxide.....	2.71						
Lime.....	14.70	6.35	9.92	10.45	8.15	12.41	10.19
Magnesia.....	4.35	2.87	15.40	10.58	5.01	12.73	13.05
Potash.....	2.01	7.42	0.47	0.61	0.86	0.32	0.31
Soda.....	4.64		3.24	3.47	3.36	1.40	1.17
Carbon dioxide.....		9.03	0.94	1.82	1.05		0.14
Water.....							

1. Birdsboro, Berks County, Pa.; H. Fleck, analyst; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 435.
2. Rushland, Bucks Co., Pa.; Lathbury & Spackman, Analysts; Min. Res. U. S., 1903, p. 155.
- 3-5. Chatham, Pittsylvania County, Va.; T. L. Watson, analyst; Min. Res. of Virginia, 1907, p. 37.
- 6-7. North of Rapidan Station, Va.; T. L. Watson, analyst; Min. Res. of Virginia, 1907, p. 39.

Physical Properties. — Since the basic rocks are not ordinarily attractive in color, there is little reason to quarry them unless they are entirely sound from a structural point of view. Com-

paratively few tests of the physical properties of basic stone are on record, but from those available it is obvious that in both strength and density they outrank the granites and other acid rocks.

TABLE 41. — PHYSICAL PROPERTIES OF AMERICAN TRAP ROCKS.

State.	Location.	Tested by	Specific gravity.	Weight per cubic foot.	Compressive strength, pounds per square inch.		
					Min.	Aver.	Max.
Connecticut	New Haven.....	Gillmore.....	2.60	162.5	.....	9.500	.....
	New Haven.....	Hawes.....	2.86	.....	.....	.....	.....
	Meriden.....	.....	2.965	.....	.....	.....	.....
Maine.....	Watertown.....	.....	.....	.....	14,161	18.801	21.035
Massachusetts.....	West Roxbury.....	.....	3.10	.....	.....	.....	.....
Minnesota.....	Duluth.....	Gillmore.....	2.802	175.1	.....	27.250	.....
	Duluth.....	Gillmore.....	2.80	175.0	.....	17.631	.....
	Tischer's Creek.....	Gillmore.....	3.005	.....	.....	.....	.....
	Taylor's Falls.....	Gillmore.....	3.000	187.5	.....	26.250	.....
	Beaver Bay.....	Gillmore.....	2.704	169.0	.....	20.750	.....
New Jersey.....	Jersey City.....	Gillmore.....	3.03	189.5	.....	21.500	.....
	Jersey City.....	Hawes.....	2.96	.....	.....	.....	.....
	Pompton.....	Gillmore.....	.....	.....	.....	24.040	.....
New York.....	Cortland Point.....	J. S. Newberry.....	.....	.....	.....	20.250	.....
	Quaker Bridge.....	.....	2.928	.....	.....	.....	.....
Pennsylvania	Rushland.....	.....	2.65	164.4	.....	.....	.....
Virginia	Chatham.....	Watson.....	2.953	.....	.....	.....	.....
	Goose Creek.....	Watertown.....	3.026	.....	.....	23.000	.....
	Rapidan.....	Watson.....	3.095	.....	.....	.....	.....

Uses of Trap Rock.— The basic igneous rocks included in this group could of course be used as building stone, or for any of the other structural uses to which granites are applied, but as a matter of fact they are rarely so used. This lack of use for these purposes is due in part to the dark and somber colors usually characteristic of the basic stones; and also, in part, to their great toughness and the consequent difficulty and expense of dressing them for structural uses. Added to these disadvantages is the tendency, shown by many of the denser basic rocks, to break on blasting into masses whose size and shape render them unfit for use as dimension stone.

On the other hand, the very features which render the traps generally unserviceable for structural purposes are of advantage

for other uses. In consequence, trap rock and allied stones are largely used as paving blocks and, in the form of crushed stone, as road metal, railway ballast and concrete aggregate. For all of these purposes darkness of color is of no disadvantage, while density, strength and toughness are of direct service.

Production of Trap Rock in the United States. — Complete statistics covering the trap-rock production of the entire United States are unfortunately not available. This condition is due to the fact that in the statistical reports on the stone industry published annually by the United States Geological Survey the production of trap is, in most of the states, included with that of granite.

The trap-rock production of the six most important producing states is, however, reported separately by the Geological Survey, and these partial statistics are quoted in the series of tables which follow.

TABLE 42. — TRAP-ROCK PRODUCTION OF THE UNITED STATES, 1899-1909.

Year.	Value.	Year.	Value.
1899	\$1,275,041	1905	\$3,074,554
1900	1,706,200	1906	3,736,571
1901	1,710,857	1907	4,594,103
1902	2,181,157	1908	4,282,406
1903	2,732,294	1909	5,133,842
1904	2,823,546	1910	6,452,121

The totals given in the preceding table, as in those which follow, cover the production of trap rock in the states of California, Connecticut, Massachusetts, New Jersey, New York and Pennsylvania only. In addition to this, trap rock is quarried more or less steadily in Maine, Minnesota, Virginia, Oregon and Washington, but no exact data on the output of these states are available.

TABLE 43. — TRAP-ROCK PRODUCTION BY STATES AND USES, 1908-1909.

1908.							
State.	Building.	Paving.	Crushed stone.			Other.	Total.
			Road-making.	Railroad ballast.	Concrete.		
California	\$722	\$114,996	\$423,798	\$148,154	\$285,380	\$6,089	\$979,139
Connecticut . . .	7,594	8,125	199,540	100,000	152,950	5,010	473,219
Massachusetts . .	12,235	.....	348,108	30,695	117,134	500	508,672
New Jersey . . .	11,399	58,169	578,570	182,355	235,967	13,054	1,079,514
New York . . . .	.....	.....	567,908	20,580	107,234	28,231	723,953
Pennsylvania . .	8,593	2,835	195,769	201,091	106,987	2,634	517,909
Total	40,543	184,125	2,313,693	682,875	1,005,652	55,518	4,282,406

1909.							
State.	Building.	Paving.	Crushed stone.			Other.	Total.
			Road-making.	Railroad ballast.	Concrete.		
California	\$900	\$129,764	\$799,846	\$71,108	\$361,255	\$108,212	\$1,471,085
Connecticut . . .	6,827	2,720	292,451	28,905	33,369	3,383	367,655
Massachusetts . .	13,250	.....	337,839	75,031	247,382	.....	673,502
New Jersey . . .	1,496	92,379	664,571	138,134	232,262	11,729	1,140,571
New York . . . .	.....	.....	662,448	27,620	70,708	.....	760,776
Pennsylvania . .	11,056	1,800	281,467	259,241	165,449	1,240	720,253
Total	33,529	226,663	3,038,622	600,039	1,110,425	124,564	5,133,842

TABLE 44. — PRODUCTION AND VALUE OF TRAP PAVING BLOCKS, 1908-1909.

State.	Paving blocks.			
	1908.		1909.	
	Number.	Value.	Number.	Value.
California	2,765,587	\$114,996	3,060,078	\$129,764
Connecticut	232,160	8,125	80,590	2,720
New Jersey	1,665,983	58,169	2,105,720	92,379
Pennsylvania	63,000	2,835	50,000	1,800
Total	4,726,730	184,125	5,296,388	226,663
Average price per thousand . . . . .	.....	38.95	.....	42.80

List of References on Trap Rock.—The following list contains the titles of a number of papers and reports dealing in one way or another with this subject. Many of the papers cited are primarily geological in their nature, and the list could have been greatly extended had more of this type been included.

California:

Anon. Trap rock in California. Bull. 38, Calif. State Mining Bureau, pp. 56-61, 154-164. 1906.

Connecticut:

Davis, W. M. The quarries in the lava beds at Meriden, Connecticut. Amer. Jour. Science, 4th series, Vol. I, pp. 1-13. 1896.

Davis, W. M. The Triassic formations of Connecticut. 18th Ann. Rep. U. S. Geol. Sur., pt. 2, pp. 9-192. 1898.

Georgia:

McCallie, S. W. Roads and road-building materials of Georgia. Bull. 8, Georgia Geol. Sur., 1901.

New Jersey:

Lewis, J. V. The origin and relations of the Newark rocks. Ann. Rep. State Geol. N. J. for 1906, pp. 99-130. 1907.

Lewis, J. V. Properties of trap rocks for road construction. Ann. Rep. State Geol. N. J. for 1906, pp. 165-172. 1907.

Lewis, J. V. Petrography of the Newark igneous rocks of New Jersey. Ann. Rep. State Geol. N. J. for 1907, pp. 97-168. 1908.

Lewis, J. V. Building stones of New Jersey. Ann. Rep. State Geol. N. J. for 1908, pp. 81-83, trap. 1909.

New York:

Eckel, E. C. The quarry industry in southeastern New York. 20th Ann. Rep. N. Y. State Museum, pp. 141-176. 1902.

Newberry, S. B. Kersantite — a new building stone. School of Mines Quarterly, Vol. VIII, pp. 330-333. 1887.

Smock, J. C. Building Stone in New York. Bulletins 3 and 10, N. Y. State Museum.

Virginia:

Watson, T. L. Mineral Resources of Virginia, 1907, pp. 36-41, trap.

CHAPTER V.

SERPENTINE AND SOAPSTONE.

Relation of Serpentine and Soapstone.—Two classes of rocks — serpentines and soapstones — will, for convenience, be considered together in the present chapter. The two classes have, in fact, many points of resemblance so far as origin and character are concerned; though industrially they are often applied to widely different uses.

Both serpentine and soapstone are hydrous magnesian silicates; and both have originated through the hydration of basic silicate rocks or minerals. Neither serpentine nor soapstone is therefore directly igneous in origin, but rather a secondary result of the alteration of an igneous (or metamorphic) rock or mineral. Their close relationship chemically, as well as their principal points of difference, are well brought out when their analyses* are compared, as below.

	Silica.	Magnesia.	Water.
	Per cent.	Per cent.	Per cent.
Serpentine.....	44.14	42.97	12.89
Soapstone (talc).....	62.00	33.10	4.90

On comparison of these analyses it will be seen that both of the rocks under consideration are, when theoretically pure, hydrous silicates of magnesia; and that they differ only in the relative proportions of their three essential constituents — silica, magnesia and combined water.

In the following sections of this chapter, the origin and characters of serpentine will first be discussed, after which a brief consideration will be given to the soapstones and allied products.

SERPENTINE.

Serpentine, Ophicalcite, and Ophimagnesite.—The term *serpentine* is applied to a series of soft greenish rocks composed largely or entirely of the mineral serpentine, which, in turn, is a

* Quoted from Kemp's "Handbook of Rocks," 3d ed., pp. 140, 141.

hydrous silicate of magnesia. The term *ophicalcite* is applied to crystalline marbles containing disseminated seams, streaks, or masses of the mineral serpentine. The term *ophimagnesite*, used in this volume for the first time, is suggested to cover the common but rarely recognized phase in which the rock is crystalline magnesite, containing disseminated serpentine.

Origin of Serpentine.— Though serpentine is not strictly speaking an igneous rock most large serpentine deposits have been derived from the alteration in place of basic igneous rocks. A few deposits (including the ophicalcites) owe their origin to a less direct process, involving the metamorphism and crystallization of an impure limestone, and the subsequent alteration of the magnesian silicate minerals developed in the crystalline marble. These two methods of origin, which differ somewhat in results as well as in process, will be briefly described below; while, for a more complete discussion of the subject reference should be made to the papers cited in the list on page 87, and particularly to those by F. J. H. Merrill and G. P. Merrill.

(1) Though other methods of origin have at times been suggested, it may be taken as proven that the bulk of the larger and purer deposits of serpentine everywhere have originated from the alteration (hydration) of basic igneous rocks, rich in magnesian silicate minerals. The particular minerals which appear to be the commonest source of serpentine are olivine, pyroxene, and hornblende.

All of the minerals named are more or less basic silicates of magnesia and iron. When subjected to surface weathering, or to the continued action of waters at or near the surface, they are decomposed with the formation of hydrated magnesium silicates and iron oxide. Among the hydrated silicates so formed, serpentine is commonly the most abundant.

(2) A second class of serpentine deposits, much less common though still of considerable commercial importance, originate in a way differing slightly in detail from that last discussed. This class includes the ophicalcites, in which serpentine masses, seams, or stringers are scattered through a ground mass of crystalline marble. In this case, the process of origin appears to have included several steps. In the first place, an impure limestone, carrying considerable silica, was metamorphosed so as to become thoroughly crystalline. During this change, the impurities of

the limestone, with possibly some additional matter from other sources, crystallized out separately in the form of various silicate minerals; so that the result of the metamorphism was the production of a crystalline marble through which were scattered crystals of hornblende, pyroxene and other silicate minerals. Later, these silicates were hydrated to serpentine, so that an opicalcite was produced.

Chemical Composition of Serpentine. — Though the chemical composition of the mineral serpentine is definite enough, wide variations in composition are shown by stones which are grouped commercially under the same name.

The two tables which follow contain a number of analyses of normal serpentines, of opicalcites and of ophimagnesites from various American localities.

TABLE 45. — ANALYSES OF SERPENTINES.

	1	2	3	4 *	5 *	6 †	7	8	9	10	11
Silica (SiO_2).....	39.48	34.84	28.80	43.87	40.06	40.39	43.72	45.02	41.55	42.60	43.30
Alumina (Al_2O_3).....		0.42	5.54	0.31	1.37	1.01	16.86	3.35			
Magnetic oxide (Fe_3O_4).....					3.02	6.22					
Ferric oxide (Fe_2O_3) }.....	20.18	6.08	3.60				tr.		3.90		
Ferrous oxide (FeO) }.....		1.85	4.75	7.17	3.43	0.97				8.30	5.32
Chromium oxide (Cr_2O_3).....		0.68	0.33		0.20	tr.					
Lime (CaO).....		7.02		0.02			2.22			0.60	
Magnesia (MgO).....	37.74	30.74	34.41	38.62	39.02	38.32	23.78	37.75	40.15	35.50	39.55
Potash (K_2O).....		0.07									
Soda (Na_2O).....		0.42					2.30				
Carbon dioxide (CO_2).....											
Water.....	1.69	17.39	20.75	9.55	12.10	12.86	11.10	13.01	13.70	13.00	11.79

* Nickel oxide, NiO , 0.71. † Nickel oxide, 0.23.

1. Auburn, Placer County, Calif.; B. S. Stone, analyst; Min. Res. U. S. 1903.
2. Monte Diablo, Calif.; Kemp's "Handbook of Rocks," 3d ed., p. 140.
3. Holly Springs, Cherokee County, Ga.; Mariner and Hoskins, analysts; letter to author, 1904.
4. Webster, N. C.; F. A. Genth, analyst; Kemp's "Handbook of Rocks," p. 140.
- 5, 6. Broad Creek, Harford County, Md.; F. A. Genth, analyst; Vol. II, Rept. Md. Geol. Sur., p. 195.
7. Near Silver City, New Mexico; Merrill, "Stone for Building and Decoration," p. 366.
8. Lancaster County, Pa.; F. A. Genth, analyst; "Mineralogy of Pennsylvania," p. 116.
9. Easton, Pa.; F. A. Genth, analyst; "Mineralogy of Pennsylvania," p. 116.
10. Roxbury, Vt.; Geology of Vermont, Vol. II, p. 779.
11. Cavendish, Vt.; Geology of Vermont, Vol. II, 779.

Regarding the analyses presented in the foregoing table (Table 45), it may be noted that analysis No. 1 is difficult to understand, even after allowing for the fact that the chemist reported it on a practically water-free basis. Analysis No. 3, of serpentine from Holly Springs, Georgia, was probably made on a badly selected sample, containing much more lime carbonate than is ordinarily carried by the stone from that quarry, which is really a very good serpentine and not an ophicalcite, as might be inferred from the analysis published.

In the following table are presented the results of analyses of serpentines and allied products from the state of Washington. This group of analyses is of peculiar interest both geologically and chemically, a fact which apparently escaped attention in its first publication. For convenience, the analyses have been arranged in an order which brings out the peculiarities of these Washington rocks, all of which were originally described as marbles. It will be seen that No. 1 is a true serpentine; that Nos. 2, 3, 4 and 5 are serpentinous limestones (ophicalcites or ophi-dolomites); that Nos. 6 and 7 are very pure magnesites; and that Nos. 8 and 9 are serpentinous magnesites or ophimagnesites.

TABLE 46. — ANALYSES OF SERPENTINES AND ALLIED ROCKS, WASHINGTON STATE.

	1	2	3	4	5	6	7	8	9
Silica.....	38.47	40.35	27.93	27.11	18.18	0.89	5.79	15.30	13.08
Alumina.....	0.16	.....	2.32	1.90	0.44	.....	0.43	3.00	1.63
Ferric oxide.....	2.04	.....	2.08	2.44	0.45	.....	0.85	3.32	1.25
Ferrous oxide.....	tr.	1.66	2.38	1.80	1.17	0.58	.....	tr.	0.19
Lime.....	.....	11.85	13.05	23.68	24.74	.....	1.69	.....	0.33
Magnesia.....	39.86	22.07	27.74	15.45	16.10	45.76	42.07	52.89	56.44
Carbon dioxide.....	4.84	17.22	11.33	19.30	38.18	49.24	47.23	1.27	2.03
Water.....	14.63	6.85	13.17	8.32	0.74	3.53	1.94	24.22	24.79

Of the above analyses, Nos. 1 to 8 inclusive were made by R. W. Thatcher; No. 8 is by George Steiger. All are quoted from Vol. II, Reports Washington State Geological Survey, pages 91 and 141. The localities are as follows:

- 1, 2. North American Marble Company, Valley, Stevens County.
3. Spokane Marble Company, Milan.
4. Pacific Coast Marble Company, Valley.
5. Washington State Marble Company, Valley.
- 6, 7, 8, 9. United States Marble Company, Valley.

Defects of Serpentine. — Though serpentine is of quite common occurrence in the regions of metamorphic and igneous rocks, workable deposits are rare, owing to certain defects which are apt to occur in this stone. These defects are directly traceable to the method by which serpentine has been formed, and therefore cannot be avoided or remedied by the quarryman. The principal common defect is that the mass of serpentine is so cut up by cracks and joints that no good-sized blocks can be obtained. The other frequent defect is that the serpentine is apt to contain little hard crystals of pyrite, chromite or magnetite. These interfere with the production of polished slabs for interior decoration, while the pyrite has the further evil effect of decomposing on exposure to the atmosphere and leaving a yellow-brown blotch of iron oxide.

Physical Properties of Serpentes. — Because of the structure of serpentines, the results of physical tests are of even less value than with other structural stones. There is no difficulty in getting out a small cube of serpentine which will show good results in the testing machine; but that is about as far as the matter goes.

In Table 48 the results of a number of tests of American serpentines of all types are quoted. For convenience, these have been averaged and compared, in the table immediately following this paragraph, with certain German tests reported by Krüger.

TABLE 47. — AVERAGE PHYSICAL PROPERTIES OF SERPENTINES.

	Specific gravity.			Weight per cu- bic foot	Compressive strength, pounds per square inch.		
	Mini- mum.	Aver- age.	Maxi- mum.	Aver- age.	Mini- mum.	Average.	Maximum.
American tests.....	2.545	2.727	2.908	170.2	8.950	11.287	14.820
German tests.....	2.560	2.727	2.894	170.2	.....	11.950	.....

The close coincidence in results of the two series of tests is an interesting accident, and should not be given too much importance.

TABLE 48. — PHYSICAL PROPERTIES OF AMERICAN SERPENTINES.

State.	Location.	Specific grav- ity.	Weight per cubic foot.	Absorption, per cent.	Compression tests.					Tested by
					Size of cube.	No. of tests.	Mini- mum.	Average.	Maxi- mum.	
California	Auburn.....	2.545	159.1	.....	In. 1½	3	.....	11,590	.....	.....
Maryland	Broad Creek....	2.668	.....	.....	.....	.....	.....	.....	.....	.....
	Broad Creek....	2.669	.....	.....	.....	.....	.....	.....	.....	.....
Texas	Gillespie Co....	2.61	159.7	0.0079	1	1	.....	8,950	.....	Univ. of Texas
Wash.	Milan, dark....	.....	.....	.....	2	3	8,210	9,520	10,400	.....
	Milan, light yel- low.....	.....	.....	.....	2	3	12,180	13,530	14,820	.....
	Valley, black....	2.908	180.3	0.14	2	2	27,800	29,750	31,700	.....
	Blue, Colville....	2.594	161.2	0.07	.....	.....	.....	.....	.....	.....
	White and yel- low, Colville....	2.720	167.2	0.12	.....	.....	.....	.....	.....	.....
	White, Colville....	2.719	166.6	0.35	.....	.....	.....	.....	.....	.....
	White, Chewe- lah.....	2.754	170.2	0.15	.....	.....	.....	.....	.....	.....
	Valley, pink and white.....	2.858	177.4	0.17	.....	.....	.....	.....	.....	.....
	Milan, white and green.....	2.696	166.3	0.33	.....	.....	.....	.....	.....	.....
	Valley, green....	.....	.....	.....	2	2	13,500	18,305	23,110	.....
	Valley, green....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Chewelah.....	2.874	178.8	0.03	2	3	14,560	17,310	20,950	.....
Germany	Bosburg.....	2.73	169.1	0.24	.....	.....	.....	.....	.....	.....
	Valley, pink....	2.829	173.8	1.32	.....	.....	.....	.....	.....	.....
	.....	2.56 }	.....	0.56 }	.....	.....	.....	.....	.....	.....
	.....	2.894 }	.....	.....	.....	.....	.....	11,950	.....	Winkler

Production of Serpentine in the United States. — In the statistical tables annually published by the United States Geological Survey the production of serpentine, "verd antique marble," etc., is included with that of marble, so that no exact data can be given in regard to the American serpentine production.

Distribution of Serpentine. — Because of their methods of origin, deposits of serpentine are confined to regions in which basic igneous rocks or highly metamorphosed limestones occur. Deposits of serpentine are therefore found in New England, the Adirondacks and Hudson Highlands of New York, and thence southward in the Highlands of New Jersey and the South Mountain, Blue Ridge and Piedmont districts of Pennsylvania, Maryland, Virginia, the Carolinas, Alabama and Georgia. Serpentine is lacking in the Ohio and Mississippi valley states, but occurs at various points in the Rocky Mountains and more western areas. The greater part of the small commercial production comes from Maryland, New York, New Jersey, Georgia,

California and Washington. For particulars concerning these localities reference should be made to the reports in the following list.

Reference List on Serpentine. — Of the papers in this list those by Mathews and Shedd are of greatest interest to the engineer and quarryman. The other papers listed deal largely or exclusively with the origin and geologic relations of serpentine.

- Burnham, S. M. History and uses of limestone and marble; 8vo., 392 pp. Boston, 1883.
- Jonas, A. J. Serpentes in the vicinity of Philadelphia. *American Geologist*, Vol. 36, pp. 296-304. Nov., 1905.
- Lyon, D. A. Serpentine marbles of Washington. *Mines and Minerals*, Vol. 21, pp. 349. 1901.
- Mathews, E. B. Character and distribution of Maryland building stones. *Reports Maryland Geol. Sur.*, Vol. 2, pp. 125-141. 1898.
- Merrill, F. J. H. The origin of the serpentine in the vicinity of New York (City). 50th Ann. Rep. N. Y. State Museum, Vol. 1, pp. 32-44.
- Merrill, G. P. On the serpentine of Montville, N. J. *Proceedings U. S. National Museum*, Vol. 11, pp. 105-111. 1889.
- Merrill, G. P. A consideration of some little known American ornamental stones. *Stone*, Vol. 19, pp. 225-230. 1899.
- Merrill, G. P. Notes on the serpentinous rocks of Essex County, N. Y., and Easton, Pa. *Proceedings U. S. National Museum*, Vol. 12, pp. 595-600. 1890.
- Newland, D. H. The serpentines of Manhattan Island and vicinity and their accompanying minerals. *School of Mines Quarterly*, Vol. 22, pp. 307-317, 399-410. 1901.
- Peck, F. B. Preliminary notes on the occurrence of serpentine and talc at Easton, Pa. *Annals of N. Y. Acad. Science*, Vol. 13, pp. 419-430. 1901.
- Peck, F. B. The talc deposits of Phillipsburg, N. J., and Easton, Pa. *Ann. Rep. N. J. State Geologist for 1904*, pp. 161-186. 1905.
- Shedd, S. The building and ornamental stones of Washington. *Ann. Rep. Washington Geol. Sur. for 1902*, Vol. 2, pp. 1-163. 1903.
- Anon. Serpentes of California. *Bull.* 38, *Cal. State Mining Bureau*, pp. 146-148. 1906.

SOAPSTONE AND ALLIED PRODUCTS.

The stones which are to be briefly described in the present section bear a certain resemblance to serpentine in origin, in composition and in physical characters.

Origin and Composition of Soapstone. — The soapstones are rocks which usually consist largely or entirely of the mineral

talc, or of some closely related mineral species. Talc is a hydrous magnesian silicate, and when theoretically pure contains approximately 63 per cent of silica, 32 per cent of magnesia, and 5 per cent of combined water. It therefore agrees with serpentine in its normal constituents, but differs from it in being both less basic and less hydrous. Both minerals have probably originated, in most cases, in the same general way, through the alteration of magnesian silicate minerals.

Some of the soapstones which are utilized commercially differ from those above noted in being composed largely of hydrous aluminum silicates; but the best-known stones are of the talcose type.

Distribution and Production. — Practically all of the talc and soapstone produced in the United States is from deposits located in the Green Mountain, Adirondack, Highland, Blue Ridge and Allegheny Mountain areas, the chief producing states being New York, Virginia and Vermont. Virginia is the principal producer of soapstone, with Vermont ranking second, for the output of New York is marketed almost entirely as ground talc.

The following statistics, taken from recent reports of the United States Geological Survey, furnish data as to the industries in question.

TABLE 49. — PRODUCTION OF TALC AND SOAPSTONE
IN THE UNITED STATES, 1880-1910.

Year.	Short tons.	Value.	Year.	Short tons.	Value.
1880-1900	969,928	\$11,224,652	1906	120,644	\$1,431,556
1901	97,843	908,488	1907	139,810	1,531,047
1902	97,954	1,140,507	1908	117,354	1,401,222
1903	86,901	840,060	1909	130,338	1,221,959
1904	91,189	940,731	1910	150,716	1,592,393
1905	96,634	1,082,062			

TABLE 50. — TALC AND SOAPSTONE PRODUCTION BY USES, 1907-1910.

Condition in which marketed.	Short tons.	Value.	Average price per ton.	Short tons.	Value.	Average price per ton.
	1907.			1908.		
Rough.....	25,538	\$34,625	\$1.36	3,013	\$7,819	\$2.60
Sawed into slabs.....	4,822	91,668	19.01	3,406	71,048	20.86
Manufactured articles *	23,484	648,475	27.61	16,336	442,624	27.10
Ground †.....	85,966	756,279	8.80	94,599	879,731	9.20
Total ‡.....	139,810	1,531,047	10.95	117,354	1,401,222	11.94
	1909.			1910.		
	Short tons.	Value.	Average price per ton.	Short tons.	Value.	Average price per ton.
Rough.....	27,412	\$79,499	\$2.90	15,425	\$56,872	\$3.69
Sawed into slabs.....	2,893	54,009	18.67	9,352	78,042	8.34
Manufactured articles *	22,646	502,447	22.19	22,363	503,391	22.51
Ground †.....	77,387	586,004	7.57	103,576	954,088	9.21
Total ‡.....	130,338	1,221,959	9.38	150,716	1,592,393	10.57

* Includes bath and laundry tubs; fire brick for stoves, heaters, etc.; hearthstones, mantels, sinks, griddles, slate pencils, gas tips, burner blanks, crayons, and numerous other articles for everyday use.

† For foundry facings, paper making, lubricators for dressing skins and leather, etc.

‡ Exclusive of the quantity used for pigment, which is included among mineral paints.

TABLE 51. — PRODUCTION OF TALC AND SOAPSTONE, BY STATES, 1908-1910.

States.	1908.		1909.		1910.	
	Short tons.	Value.	Short tons.	Value.	Short tons.	Value.
Massachusetts....	(*)	(*)	9,057	\$48,729	7,475	\$52,204
New Jersey and Pennsylvania....	4,648	\$29,118	13,900	61,967	13,192	62,833
New York.....	70,739	697,390	48,536	359,957	71,710	728,180
North Carolina....	3,564	51,443	5,956	77,983	3,887	69,805
Vermont.....	10,755	99,743	23,626	120,329	25,975	136,674
Virginia.....	19,616	458,252	26,511	523,942	25,908	510,781
Other States †....	8,032	65,276	2,752	29,052	2,569	31,916
Total.....	117,354	1,401,222	130,338	1,221,959	150,716	1,592,393

* Included in "Other States."

† Georgia, Maryland, Massachusetts and Rhode Island, in 1908; California, Georgia, Maryland and Rhode Island, in 1909 and 1910.

TABLE 52. — TALC IMPORTED INTO THE UNITED STATES, 1902-1910.

Year.	Short tons.	Value.	Average price per ton.	Year.	Short tons.	Value.	Average price per ton.
1902	2,859	\$35,366	\$12.36	1907	10,060	\$126,391	\$12.56
1903	1,791	19,677	10.99	1908	7,429	97,096	13.07
1904	3,268	36,370	11.13	1909	4,417	56,287	12.74
1905	4,000	48,225	12.05	1910	8,378	106,460	12.71
1906	5,643	67,818	12.02				

References on Talc and Soapstone. — The following list contains the titles of a number of papers and reports which can be consulted for further data on talc and soapstone, to supplement the necessarily brief discussion in the present volume.

- Keith, A. Talc deposits of North Carolina. Bull. 213, U. S. Geol. Sur., pp. 433-438. 1903.
- Nevius, J. N. Fibrous talc in St. Lawrence County, New York. Eng. & Mining Jour., Vol. 67, pp. 234, 235. 1899.
- Nevius, J. N. The talc industry of St. Lawrence County, New York. 51st Ann. Rep. N. Y. State Museum, Vol. 1, pp. 122-127. 1899.
- Peck, E. B. The talc deposits of Phillipsburg, N. J., and Easton, Pa. Ann. Rep. N. J. State Geologist for 1904, pp. 161-186. 1905.
- Pratt, J. H. Talc and pyrophyllite deposits in North Carolina. Economic Paper, No. 3, N. C. Geol. Sur., 29 pp. 1900.
- Sahlin, A. The talc industry of the Gouverneur district, New York. Trans. Amer. Inst. Min. Eng'rs, Vol. 21, pp. 583-588. 1893.
- Smyth, C. H. Report on the talc industry of St. Lawrence County, N. Y. 15th Ann. Rep. N. Y. State Geologist, Vol. 1, pp. 661-671. 1897.
- Perkins, G. H. Soapstone in Vermont. Rep. Vt. State Geologist for 1899-1900, pp. 77-79. 1900.
- Watson, T. L. Talc and soapstone in Virginia. Mineral Resources of Virginia, Richmond, 1907, pp. 289-296.

CHAPTER VI.

SEDIMENTARY ROCKS IN GENERAL.

THE products which have been discussed in the preceding chapters of this volume are all, either directly or indirectly, of igneous origin. The stones which remain to be considered — the slates, sandstones, limestones and marbles — are, on the other hand, of sedimentary origin. In order to keep a proper sense of proportion it seems desirable, before taking up the classes of sedimentary rocks separately, to devote a short chapter to the consideration of the entire group. It will thus be possible to discuss both the resemblances of the group, and the differences of the sub-classes, from a broader basis than is available when only one of the sub-classes is under consideration.

The Basis for Classification. — Geologists and petrographers who have devoted most of their lives to the study of the igneous rocks, have fallen into one curious error of fact with regard to the sedimentary rocks. When an error once reaches the dignity of print, it is capable of a surprising tenacity of life; for the human parrots who are responsible for much of our literature rarely check up their compilations by either research or thought. The result, in this particular case, is the common assumption that the classification of the sedimentary rocks is less natural and less exact than that of the igneous rocks.

In every publication on the subject that has come to the notice of the writer, the assumption is made, either explicitly or implicitly, that the various classes of sedimentary rocks show such an infinite series of gradations, so far as chemical composition is concerned, as to render a sharply defined classification impossible. In this respect the sedimentary rocks are invariably contrasted unfavorably with the igneous rocks, where such definite classification is held to be possible. As a matter of fact, the real conditions are exactly the reverse of those set forth by our textbook writers, for it is the sedimentary rocks which show the sharpest chemical differences, and the greatest gaps between

classes. It is therefore feasible to classify sedimentary rocks on a purely chemical basis; and in the classification thus established relatively few intermediate links will be found.

Classes of Sedimentary Rocks. — A convenient working classification of the sedimentary rocks, satisfactory enough for our present purposes, is that following. It will be seen that these rocks can be divided into three fairly distinct groups, the basis for the division, as given below, being partly chemical and partly physical. In later sections the sharpness of the chemical distinctions between the groups will be more strikingly illustrated.

(1) *Siliceous* sediments; composed of grains or pebbles, usually of quartz — *sandstones, conglomerates*.

(2) *Argillaceous* sediments; composed of clayey materials — *shales, slates*.

(3) *Calcareous* sediments; composed largely or entirely of carbonate of lime, with or without carbonate of magnesia — *limestones, dolomites, marbles*.

Degree of Consolidation. — It may here be noted that the geologist, in speaking of *rocks*, includes not only the hard materials commonly known by that name but also the soft, unconsolidated phases of these same materials, i.e., sands, gravels, clays, marls, etc. This introduces a cross classification, based on the degree of consolidation of the material, as indicated in the little table following:

Kind of rock.	Degree of consolidation.		
	Entirely unconsolidated.	Normally consolidated.	Metamorphosed, extremely consolidated.
Siliceous rocks. . . .	Sand, gravel	Sandstones, conglomerates.	Quartzites
Argillaceous rocks.	Clays	Shales	Slates, schists
Calcareous rocks. .	Marls	Limestones	Marbles

Modes of Origin of Sediments. — With the exception of a few relatively unimportant instances where ice or wind have played some part in the deposition of rocks, all of the sedimentary rocks have been deposited in bodies of water. In most cases water has been both the transporting and the depositing agent, but chemical and organic agencies have in many instances affected the result.

In the case of a sandstone deposit, for example, the sand grains of which it is composed were transported by flowing water to some point at which the current was checked. The deposition of the sand took place, therefore, from purely mechanical causes. Clay and shale beds are, in most cases, due to causes just as purely mechanical as are the sand beds.

In the case of limestones, however, two entirely different sets of agencies have often taken part in the process. This arises from the fact that lime carbonate, as transported by running water, is carried in solution and not in suspension. The simple checking of the current will therefore be insufficient, under ordinary conditions, to produce the deposition of limestone. Such deposition can be caused, however, either by chemical agencies acting on the lime-charged water, or by the action of organisms. In one case the lime carbonate may be deposited through evaporation; in the other case it may be extracted from the water by organisms, and will then form a bed of limestone when these organisms finally sink to the bottom.

Characteristic Sedimentary Structures. — The most characteristic feature about sedimentary rocks, as distinguished from igneous rocks, is the fact that the sediments are almost invariably divided into beds or layers. This characteristic feature arises from the fact that sedimentation is never absolutely continuous and uniform. Variations in the water level, in the direction of currents, or in composition of the particles of material carried by the water in suspension — all of these have an influence in this matter. Even slight changes in the composition of the deposit are apt to be reflected by differences of color, texture, etc., which suffice to mark out the bedding planes of the resulting rock.

Metamorphism and Its Effects. — The metamorphism of sedimentary rocks changes their character and appearance in many ways, but these changes are usually almost entirely physical, and are accompanied by less chemical alteration than might be supposed. This point is brought out conclusively in later chapters where the alteration of limestone to marble, of clayey sediments to slates, and of sandstones to quartzites are discussed in some detail.

Normal Order of Discussion. — In the succeeding chapters of this volume the sedimentary building stones will be taken up

separately and described in detail. The order in which these sub-classes will be discussed is as follows:

Chapter VII. — Slates.

Chapter VIII. — Sandstones.

Chapter IX. — Limestones.

Chapter X. — Marbles.

This order of discussion is the normal one to adopt, if the origin and general relations of these sub-classes be kept in mind. The slates are, so far as genesis and chemical composition are concerned, the most closely related to the igneous rocks and should therefore be considered first. The sandstones and limestones, on the other hand, represent products whose composition has, by mechanical or chemical selection, become sharply differentiated from that of the average igneous rock.

CHAPTER VII.

SLATES.

THE slates are rocks, normally clayey in composition, in which pressure has produced a very perfect cleavage, so that a block of slate can be readily split into thin, smooth, tough plates.

ORIGIN AND COMPOSITION.

Origin of Slates. — Almost all commercial slates have originated through the action of pressure on fine-grained, clayey sedimentary rocks; but a few well-known roofing slates have been produced, by the same agency, from deposits of volcanic ash or from rocks of even more direct igneous origin. Though these igneous slates are of great interest scientifically, the normal or clayey slates are much more important. The following discussion, therefore will consider primarily the origin of the clay slates, after which the origin of the igneous slates will be briefly noted. Wherever, in this chapter, the term *slate* is used without any qualification, it should be understood to refer to the slates derived from sedimentary clay rocks.

The first stage in the origin of a slate is the deposition, in relatively quiet water, of fine-grained clayey material. No conceivable pressure can succeed in making a serviceable slate out of a coarse-grained sediment, out of a bed of sand, or out of a noticeably calcareous deposit. So that unless the original sedimentary deposit is of the proper physical constitution, no slate deposit can be formed from it. Now, it happens that the proper fineness and plasticity can be readily secured in deposits of clay, but that they are very difficult and almost impossible to secure if the deposit consists of siliceous or limy matter. For this reason, slates show a surprising uniformity in chemical composition — a fact which usually is either overlooked or passed by as a matter of course.

If the clay bed so formed be allowed to consolidate under entirely normal conditions, a bed of shale will be the ultimate

result. This will carry almost as much combined water as did the original clay, will have practically the same mineral constitution, and will show no regular cleavage system, breaking on the contrary into irregular blocks. In a later section of this volume, when dealing with the subject of clays, further data on shale deposits will be presented. At present, however, their interest arises from the fact that many of them might have become slates under more favorable conditions.

In regions where earth movements have exerted heavy and long-continued pressure on the rocks, certain physical and chemical changes have often been the results. The limestones may be recrystallized into marbles; the sandstones may become quartzites; and some of the fine-grained clayey rocks may become slates. In all of these metamorphic effects, the physical changes are the more important and noticeable; but in some instances chemical changes have also accompanied them. In the case of the formation of slates the physical changes are the only ones which really require consideration at any length.

The chief difference between a roofing slate and an ordinary clay or shale is that the slate will cleave readily into thin plates, which plates may or may not be parallel to the original bedding planes, while the clays and shales break into more irregular masses, the easiest breaking planes being either parallel to the bedding or parallel to joint systems. It has been proven experimentally that the distinctive *slaty cleavage* can be produced in any fine-grained homogeneous mass by long-continued heavy pressure, so that we may fairly assume that the cleavage of roofing slates is produced in this way. The character of this cleavage, and its relation to the original bedding planes, will be discussed on a later page.

Average Chemical Composition of Slates.— The following average analysis of roofing slate has been prepared by the writer from a long series of analyses of commercial slates quarried in various American districts.

TABLE 53. — AVERAGE COMPOSITION OF FORTY-SEVEN AMERICAN ROOFING SLATES.

Constituent.	Number of determinations averaged.	Minimum.	Average.	Maximum.
Silica.....	44	54.05	61.43	69.08
Alumina *.....	43	8.62	17.33	24.71
Ferric oxide.....	20	0.52	2.24	7.10
Ferrous oxide.....	20	0.97	3.85	7.48
Lime.....	45	0.00	1.58	5.23
Magnesia.....	45	0.12	2.47	6.43
Potash.....	36	0.72	3.46	5.54
Soda.....	36	0.09	1.11	3.15
Iron sulphide.....	18	.....	0.38	.....
Carbon dioxide.....	16	.....	1.47	.....
Combined water.....	15	.....	3.51	.....
Moisture.....	16	.....	0.62	.....
Total silica and alumina..	47	.....	78.76	.....
Total iron oxides.....	44	.....	7.40	.....
Total lime and magnesia..	45	.....	4.05	.....
Total alkalis.....	40	.....	4.47	.....
Total water and CO ₂	16	.....	5.60	.....

* Titanic oxide is included with the alumina in this table. In nineteen of the analyses considered, the titanic oxide had been separately determined. The average of these nineteen determinations gave 0.73 per cent titanic oxide.

Average Composition of Shales. — In Bulletin 168, United States Geological Survey, on pages 16 and 17, Dr. Clarke has quoted a series of composite analyses of American sedimentary rocks. The material was selected and the samples were prepared by Mr. G. K. Gilbert, assisted by Mr. G. W. Stose, and the analyses were made by Dr. H. N. Stokes in the chemical laboratory of the Survey.

These composite analyses, so far as they relate to shales, are reprinted here as Table 54. The determinations of a number of minor constituents are omitted. In this series each individual shale was taken in amount roughly proportional to the mass of the formation which it represented. The samples were then mixed into one uniform sample from which, by a single analysis, an average composition was determined.

In column 1 is given the result of an analysis of twenty-seven Mesozoic and Cenozoic shales; and in column 2 that of fifty-one Paleozoic shales. Column 3 gives the average of these two determinations, giving them, respectively, weights as 3 to 5.

The values in this column are, therefore, an approach to the "average shale" composition.

TABLE 54. — COMPOSITE ANALYSES OF AMERICAN SHALES.

	1	2	3
Silica (SiO_2).....	55.43	60.15	58.38
Alumina (Al_2O_3).....	13.84	16.45	15.47
Titanic oxide (TiO_2).....	0.46	0.76	0.65
Ferrous oxide (FeO).....	1.74	2.90	2.46
Ferric oxide (Fe_2O_3).....	4.00	4.04	4.03
Lime (CaO).....	5.96	1.41	3.12
Magnesia (MgO).....	2.67	2.32	2.45
Potash (K_2O).....	2.67	3.60	3.25
Soda (Na_2O).....	1.80	1.01	1.31
Carbon dioxide.....	4.62	1.46	2.64
Water of combination.....	3.45	3.82	3.68
Moisture, below 110°C	2.11	0.89	1.34

It may be noted in passing that some of the differences in composition between the Paleozoic and the later shales were, either in degree or in kind, contrary to what might have been expected, from a purely theoretical standpoint.

Comparison of Slate and Shale Average Analyses. — It is of interest to compare the two long series of slate and shale analyses presented in the two preceding sections, with a view to getting some idea of the relative chemical composition of the two classes of rock. As almost all of the slate analyses were of Paleozoic slates, it is obvious that the average slate should be most directly comparable with the composite analysis of fifty-one Paleozoic shales, given in column 2 of Table 54. The necessity for thus restricting the comparison is accentuated by the fact, above intimated, that the Paleozoic and later shales are not themselves directly comparable.

The average slate contains 61.43 per cent of silica, as against 60.15 in the average Paleozoic shale. Alumina and titanic oxide together amount to 17.33 in the slate, and to 17.21 in the shale, the titanic oxide alone being practically the same in both. The slate is high in ferrous oxide, and the shale in ferric oxide; but the total iron oxides in the slate amount to 7.40 per cent, as against 6.94 in the shale. Lime and magnesia together are 4.05 in the slate, and 3.73 in the shale; and total alkalis are still closer, being 4.47 in the slate, and 4.61 in the shale. Carbon

dioxide, combined water and moisture are also almost exactly the same in the two rocks. Carbonates, as rock-forming minerals, introduce an element of weakness: and their presence in undue quantity in any given slate must therefore be regarded with suspicion.

The conclusion to be drawn from this comparison is that the average roofing slate is almost absolutely identical in chemical composition with the average shale; and that the two differ only in their physical characters. During the change from shale to slate — or rather from clay to slate or shale — the slate assumed perfect cleavage, but its composition was practically unaltered.

Origin and Composition of Igneous Slates. — There are two classes of slates now quarried to both of which the term *igneous slates* may be fairly applied, though they are really very different in origin. The first class would include slates formed from deposits of volcanic ash; the second class would include slates formed from actual igneous rocks.

(1) The *ash slates* have been known and quarried for a long time, the best-known examples of this type being the slates from the Lake district of England. Dale* has summarized recently published descriptions of these slates as follows:

“Most remarkable are the green slates from the English Lake district (Buttermere, Tilberthwaite, etc.), which consist of volcanic ash and which have long been known in England as excellent roofing material. These have recently been chemically and microscopically analyzed and described. These slates are found to consist chiefly of chlorite, calcite, quartz (mostly secondary), and muscovite, but contain also andesitic lapilli, feldspar, garnets, sphene and anatase. Slate needles and tourmaline are conspicuously absent. The chemical analyses show the following important constituents:

SiO ₂	50.16–54.02
Al ₂ O ₃	11.94–17.85
CaO	3.67– 6.46
FeO	5.97– 7.06
CO ₂	2.45– 5.41

CO₂ if calculated to CaCO₃ would give from 5.56 to 12.29 per cent of CaCO₃. Specific gravity ranges from 2.775 to 2.788.

* Bull. 275, U. S. Geol. Sur., p. 18. 1906.

The percentage of SiO_2 is low, and that of FeO is near that of the "unfading green" slate of Vermont."

(2) The *sheared igneous slates* are a still more remarkable class. These were first identified and described* by the present writer in 1903, who found them worked at the quarry of the Eureka Slate Company, north of Placerville, California. The igneous slates here appear as narrow bands extending vertically from top to bottom of the quarry wall, the main mass of the wall being a glossy black slate of normal sedimentary origin.

A typical specimen of the green slate, from near the middle of the band, was selected for partial analysis in the laboratory of the United States Geological Survey, and the results of this analysis are presented below, as No. 1. The second analysis given below was quoted to the writer by Mr. C. H. Dunton, manager of the Eureka Slate Company, but the name of the analyst was unknown to him. The two analyses agree sufficiently closely, and are probably fairly representative of the chemical composition of the green slates.

ANALYSES OF THE "GREEN SLATES" FROM SLATINGTON, CALIFORNIA.

	1	2
Silica (SiO_2).....	45.15	47.30
Alumina (Al_2O_3) and titanite oxide (TiO_2).....	16.33	15.53
Iron oxides (FeO , Fe_2O_3).....	8.42	8.00
Lime (CaO).....	6.42	7.83
Magnesia (MgO).....	8.72	7.86
Alkalies (Na_2O , K_2O).....	n.d.	3.17
Carbon dioxide (CO_2) }	11.28	9.92
Water..... }		

1. By W. T. Schaller, U. S. Geological Survey Laboratory.

2. Analyst unknown. Analysis quoted by Eureka Slate Co.

It will be seen that these analyses differ widely from those of any normal clay slate, and even if no structural evidence were at hand, the chemical composition of the green slate would be sufficient to suggest that their origin was probably from igneous, not sedimentary, rocks.

* Eckel, E. C. On a California roofing slate of igneous origin. *Journal of Geology*, Vol. XII, pp. 15-24.

The evidence gathered as a result of further study of this occurrence may be summarized as follows:

1. The structural relations of the green and the black slates seem to prove that the green slates are derived, by dynamic metamorphism, from an igneous rock; further, that this rock was an intrusive massive rock, not an interbedded tuff; and that it was intruded into the Mariposa slates at some period subsequent to their deposition, but before their assumption of slaty cleavage.

2. Microscopic evidence, though inconclusive, owing to the lack of a sufficient supply of material, proves that the green slates are composed of thoroughly crystalline material. The rock forming one of the near-by dikes is shown to be a gabbro.

3. Chemical analyses of the green slates show that they are widely different in composition from the black slates, and, indeed, from any normal clay slate. Comparison of the same analyses with those of igneous rocks of the region show striking similarities in composition between the green slates and certain massive, basic, igneous rocks — gabbros and allied rocks.

There are, of course, no reasons why an igneous rock should not be susceptible of change, under proper conditions, into a roofing slate; and the possibility of such a change occurring would probably have been conceded by most geologists, had the question been brought to their attention, before the foregoing description of an actual occurrence had been published. Notwithstanding these facts, the California occurrence seems to be unique. The extensive literature of roofing slate has been examined by the writer, so far as this literature is available, and no similar occurrences of the derivation of roofing slates from massive igneous rocks have been noted. More than this, the possibility of such an occurrence would seem to have been overlooked by most writers, who either expressly or by implication use the term "roofing slate" to include only argillaceous sedimentary rocks. This oversight is the more inexcusable, because a large industry has been based for a century or more, in one English district, on roofing slates derived from tuffs.

List of References on Origin and Composition of Slate. — The following list covers a few of the many papers dealing with the origin and composition of slates.

- Becker, G. F. Finite homogeneous strain, flow, and rupture of rocks. *Bull. Geol. Soc. America*, vol. 4, pp. 13-90. 1893.
- Becker, G. F. Schistosity and slaty cleavage. *Jour. of Geol.*, vol. 4, pp. 429-448. 1896.
- Becker, G. F. Experiments on schistosity and slaty cleavage. *Bull.* 241, *U. S. Geol. Sur.* 1904.
- Cole, G. Phyllade, phyllite, and ottrelite. *Geol. Mag.*, new series, decade IV, vol. 3, pp. 79-81. 1896.
- Dale, T. N. Slate deposits and slate industry of the United States. *Bull.* 275, *U. S. Geol. Sur.*, 154 pp. 1906.
- Eckel, E. C. On the chemical composition of American shales and roofing slates. *Jour. of Geol.*, vol. 12, pp. 25-29. 1904.
- Eckel, E. C. On a California roofing slate of igneous origin. *Jour. of Geol.*, vol. 12, pp. 15-24. 1904.
- Harker, A. On slaty cleavage and allied rock structures. *Rep. British Assoc. Adv. Science for 1885.* 1886.
- Hunt, A. R. Notes on petrological nomenclature; schist, slate, phyllade, and phyllite. *Geol. Mag.*, new series, decade IV, vol. 3, pp. 31-35. 1896.
- Hutchings, W. M. Notes on the probable origin of some slates. *Geol. Mag.*, new series, decade III, vol. 7, pp. 264-273, 316-322. 1890.
- Hutchings, W. M. Notes on the ash slates and other rocks of the Lake district. *Geol. Mag.*, new series, decade III, vol. 9, pp. 154-161, 218-228. 1892.
- Hutchings, W. M. Notes on the composition of clays, slates, etc.; and on some points in their contact metamorphism. *Geol. Mag.*, new series, decade IV, vol. 1, pp. 36-45, 64-75. 1894.
- Hutchings, W. M. An interesting contact rock. with notes on contact metamorphism. *Geol. Mag.*, new series, decade IV, vol. 2, pp. 122-131, 163-169. 1895.
- Hutchings, W. M. Note on a contact rock from Shap. *Geol. Mag.*, new series, decade IV, vol. 2, pp. 314-317. 1895.
- Hutchings, W. M. Clays, shales, and slates. *Geol. Mag.*, new series, decade IV, vol. 3, pp. 309-317, 343-350. 1896.
- Hutchings, W. M. The contact rocks of the great Whin Sill. *Geol. Mag.*, new series, decade IV, vol. 5, pp. 69-82, 123-131. 1898.
- Reade, T. M., and Holland, P. The green slates of the Lake district, with a theory of slaty cleavage and slaty structure. *Proc. Liverpool Geol. Soc.* for 1900-1901, pp. 101-127. 1901.
- Spring, W. Sur les conditions dans lesquelles certains corps prennent la texture schisteuse. *Archives des sciences phys. et nat. de Geneve*, vol. 13, pp. 329-341. 1893.

Analyses of Slates from Various Localities.— The following series of tables (Tables 55 to 61 inclusive) contain the results of a large number of analyses of roofing slates from various localities in the United States and elsewhere.

TABLE 55. — ANALYSES OF SLATES: MAINE AND MASSACHUSETTS.

	1	2	3
Silica.....	56.42	54.24	60.80
Alumina.....	24.14	24.71	22.00
Ferric oxide.....	4.46	8.39	10.50
Lime.....	0.52	5.23	0.50
Magnesia.....	2.28	2.59	0.70
Potash.....	5.53	0.72	1.50
Soda.....	3.15	1.43	0.80

1. Monson Slate Company, Monson, Me.; L. M. Norton, analyst; 20th Ann. Rep. U. S. Geol. Survey, pt. 6, p. 394.
2. Monson, Me.; no analyst given; quoted in same publication.
3. Lancaster, Mass.; no analyst; 18th Ann. Rep. U. S. Geol. Sur., pt. 5, p. 999. Probably mica schist.

TABLE 56. — ANALYSES OF SLATES: NEW YORK, VERMONT.

	1	2	3	4	5	6	7	8	9
Silica.....	67.61	67.55	56.49	63.88	67.89	59.27	60.24	60.96	61.63
Alumina.....	13.20	12.59	11.59	9.77	11.03	18.81	18.46	16.15	16.33
Titanic oxide.....	0.56	0.58	0.48	0.47	0.49	0.99	0.92	0.86	0.68
Ferric oxide.....	5.36	5.61	3.48	3.86	1.47	1.12	2.56	5.16	4.10
Ferrous oxide.....	1.20	1.24	1.42	1.44	3.81	6.58	5.18	2.54	2.71
Lime.....	0.11	0.26	5.11	3.53	1.43	0.42	0.33	0.71	0.50
Magnesia.....	3.20	3.27	6.43	5.37	4.57	2.21	2.33	3.06	2.92
Potash.....	4.45	4.13	3.77	3.45	2.82	3.75	4.09	5.01	5.54
Soda.....	0.67	0.61	0.52	0.20	0.77	1.88	1.57	1.50	1.26
Iron sulphide.....	0.03	0.04	0.03	tr.	0.04	0.15	0.16	.....	0.04
Carbon dioxide.....	.....	0.11	7.42	5.08	1.89	0.21	0.08	0.68	0.41
Water.....	3.42	3.43	3.19	2.75	3.57	4.30	3.99	3.25	3.55

	10	11	12	13	14	15	16	17
Silica.....	65.29	59.70	59.84	62.37	67.76	59.48	60.72	58.15
Alumina.....	16.98	15.02	15.43	14.12	18.22	22.59	18.93
Titanic oxide.....	0.79	0.74	0.74	0.71	1.02	0.57	0.93
Ferric oxide.....	0.52	1.23	1.34	0.81	1.24	.....	2.91
Ferrous oxide.....	4.88	4.73	5.34	4.71	6.81	6.03	5.64
Lime.....	1.27	2.20	0.77	0.63	0.56	0.41	0.60
Magnesia.....	3.23	3.41	3.14	2.38	2.50	2.05	2.70
Potash.....	3.77	4.48	4.20	3.52	3.81	3.69	3.92
Soda.....	1.35	1.12	1.14	1.39	1.55	0.86	1.17
Iron sulphide.....	1.18	0.05	0.06	0.22	0.13	n.d.	n.d.
Carbon dioxide.....	1.40	2.98	0.87	0.40	0.39	n.d.	n.d.
Water.....	4.12	3.85	4.05	3.21	4.22	3.01	4.56

Analyses 1-15 inclusive of the above table are by W. F. Hillebrand, and are quoted from the nineteenth Annual Report United States Geological Survey, part 3, page 232, *et seq.* Analyses 16 and 17 are by L. G. Eakins, and are quoted from Bulletin 168, United States Geological Survey, page 280. The localities are as follows:

1. Red slate, Matthews quarry, Poultney, Washington County, New York.
2. Red slate, Empire Red Slate Company, Granville, N. Y.
- 3, 4. Red slate, National Red Slate Company, Raceville, N. Y.
5. Green slate, National Red Slate Company, Raceville, N. Y.
6. Unfading green slate, Eureka quarries, Poultney, Vt.
7. Variegated slate, Eureka quarries, Poultney, Vt.
8. Purple slate, Francis quarry, Hydeville, Vt.
9. Purple slate, McCarthy quarry, Lake St. Catharine, Vt.
10. Sea-green slate, Auld & Conger quarry, Wells, Vt.
11. Black slate, American Black Slate Company, Benson, Vt.
12. Sea-green slate, Hughes quarry, Pawlet, Vt.
13. Sea-green slate, Griffith quarry, South Poultney, Vt.
14. Sea-green slate, Rising & Nelson quarry, West Pawlet, Vt.
15. Unfading green slate, Valley Slate Quarry Company, Poultney, Vt.
16. Slate, Guilford, Vt.
17. Slate, Lake Shore quarry, Hydeville, Vt.

TABLE 57. — ANALYSES OF SLATES: NEW JERSEY, PENNSYLVANIA, MARYLAND.

	1	2	3	4	5	6	7	8	9
Silica.....	58.37	55.88	60.32	56.85	56.38	68.62	90.97	90.09	89.27
Alumina.....	21.98	21.85	23.10	15.24	15.27	12.68			
Titanic oxide....	n.d.	1.27	n.d.	0.84	0.78	n.d.			
Iron oxides.....	10.66	9.03	7.05	5.52	4.90	4.20	1.13	2.07	2.67
Lime.....	0.30	0.16	.....	4.24	4.23	1.31			
Magnesia.....	1.20	1.50	0.87	2.93	2.84	1.80	2.48	2.57	0.93
Potash }	1.93	{ 3.64	3.83	2.34	3.51	3.73	n.d.	n.d.	n.d.
Soda }		{ 0.46	0.49	1.38	1.30		n.d.	n.d.	n.d.
Iron sulphide....	0.11	0.05	0.09	1.72	1.72	n.d.	n.d.	n.d.	n.d.
Carbon dioxide....	0.39	n.d.	n.d.	3.58	3.67	2.99	n.d.	n.d.	n.d.
Water.....	4.03	3.39	4.08	n.d.	4.86	4.47	n.d.	n.d.	n.d.

Of the above analyses, 1-3 are of slates from the Peachbottom district in Maryland and Pennsylvania; 4-6 are from the Lehigh or Slatington district of Pennsylvania; and 7-9 are from the New Jersey continuation of the last-mentioned region.

1. Harford County, Md.; Booth, Garrett & Blair, analysts; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 399.
2. Humphreys quarry, Delta, York County, Pa.; A. S. McCreath, analyst; *ibid.*, p. 436.
3. Lancaster County, Pa. Quoted by Merrill, "Stones for Building and Decoration."
4. Washington vein, Hazel Hill quarry, Slatington, Pa.; W. F. Hillebrand, analyst; Bull. 275, U. S. Geol. Sur., p. 84.
5. Lower Franklin vein, old Franklin quarry, Slatington, Pa.; *ibid.* †
6. East Bangor, Northampton County, Pa.; H. Leffman, analyst; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 436.
7. Springdale, N. J.; Ann. Rep. N. J. State Geol. for 1900, p. 78.
8. Newton, N. J.; Ann. Rep. N. J. State Geol. for 1900, p. 77.
9. Lafayette, N. J.; Ann. Rep. N. J. State Geol. for 1900, p. 74.

TABLE 58. — ANALYSES OF SLATES: VIRGINIA, TENNESSEE, GEORGIA.

	1	2	3	4	5	6	7	8
Silica.....	55.58	56.33	60.65	54.76	58.45	59.00	58.20	57.40
Alumina.....	24.53	22.26	16.87	24.11	21.88	23.44	18.83	23.65
Ferric oxide.....	0.11	5.21	7.79	n.d.	6.04	6.28	n.d.	4.45
Ferrous oxide.....	8.70	4.23	n.d.	n.d.	n.d.	n.d.	5.78	n.d.
Lime.....	0.42	0.68	1.91	n.d.	1.86	1.30	4.35	3.23
Magnesia.....	1.95	1.48	2.39	n.d.	0.46	0.50	3.51	3.23
Potash.....	3.17	3.58	3.80	n.d.	1.60	2.04	2.51	n.d.
Soda.....	1.71	1.49	2.18	n.d.	2.34	1.78	0.69	n.d.
Sulphur.....	0.008	0.004	0.69	n.d.	0.65	0.23	0.49	n.d.
Carbon dioxide....	1.99	1.69	n.d.	n.d.	n.d.	n.d.	0.60	6.80
Combined water...	3.39	2.86	3.63	n.d.	6.66	4.64	4.07	

1. Green slate, Standard Slate Company, Esmont, Albemarle County, Va.; sampled by E. C. Eckel, analyzed by Lehigh Valley Testing Laboratory.
2. Black slate, same quarry, sampler, and analyst as preceding.
3. Gray slate, Williams quarry, Arvonja, Buckingham County, Va.; H. Froehling, analyst; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 458.
4. Slate, near Warrenton, Fauquier County, Va.
- 5, 6. Slate from quarry Southern Slate Company, Maryville, Blount County, Tenn.; analyzed by G. McCulloch; quoted in Bull. 275, U. S. Geol. Sur., p. 88.
7. Slate, Georgia Slate Company, Rockmart, Polk County, Ga.; Slocum & VanDeventer, analysts; 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 376.
8. Slate, Southern States Portland Cement Company; J. F. Davis, analyst; Bull. 275, U. S. Geol. Sur., p. 60.

TABLE 59. — ANALYSES OF SLATES: ARKANSAS.

	1	2	3	4	5	6	7	8	9	10
Silica.....	53.81	54.83	68.90	57.79	69.76	52.50	55.71	53.23	52.35	52.79
Alumina.....	25.40	23.53	14.03	22.92	14.16	26.31	25.20	26.29	26.16	24.96
Ferric oxide.....	6.17	5.06	.....	5.19	.....	3.98	2.46	3.81	5.81	6.27
Ferrous oxide.....	2.75	3.41	4.65	2.62	4.58	5.34	3.97	4.21	3.16	3.81
Lime.....	0.31	0.28	0.37	0.23	0.38	0.28	0.26	0.31	0.29	0.28
Magnesia.....	1.74	3.05	1.11	1.97	1.32	2.27	1.74	1.87	2.29	1.69
Potash.....	4.27	3.21	2.14	4.66	1.94	3.32	4.51	3.58	3.82	3.52
Soda.....	0.49	0.21	0.05	0.12	0.13	0.04	0.22	tr.	0.16	0.03
Carbon dioxide	4.62	6.01	7.69	4.13	7.44	5.33	5.13	5.82	5.19	5.79
Combined water										
Organic matter										
Moisture.....	0.66	0.43	0.66	0.48	0.54	0.47	0.53	0.59	0.57	0.72

	11	12	13	14	15	16	17
Silica (SiO ₂).....	66.16	68.79	69.04	69.07	67.90	64.00	63.22
Alumina (Al ₂ O ₃).....	8.62	14.26	12.66	11.40	10.42	11.59	16.76
Ferric oxide (Fe ₂ O ₃).....	9.04	5.90	8.55	7.66	6.22	13.71	9.54
Ferrous oxide (FeO).....	3.44	1.16	1.30	1.04	.....	.....	.....
Lime (CaO).....	1.77	1.40	1.75	1.56	3.17	1.56	1.75
Magnesia (MgO).....	.78	1.43	1.87	3.14	4.34	2.03	1.52
Potash (K ₂ O).....	4.96	3.09	2.98	3.88	4.11	1.36	1.43
Soda (Na ₂ O).....	.64	.09	.09	.96	.69	.64	.07
Sulphur in SO ₃.....	.08	.44	.06	.02	.06	.05	.05
Sulphur in FeS ₂.....	.02	.01	.01	.01	.01	.04	.03
Carbon (C).....	2.10	2.01	tr.	.....	1.78	4.03	3.70
Carbon dioxide (CO ₂).....	.09	.11	.72	.11	.01	.01	.01
Water.....	.18	.47	.84	.24	.23	.57	1.01

Analyses 1-10 inclusive of the preceding table were made at a laboratory formerly maintained in St. Louis by one branch of the United States Geological Survey, but not manned by Survey chemists. The analyses are quoted from Bulletin 430, United States Geological Survey, page 334, and are repeated here for what they may be worth. In the writer's opinion they are as doubtful as those formerly turned out at the Watertown Arsenal.

Analyses 11-17 are quoted from Bulletin 275, United States Geological Survey, page 53, where they are credited to W. G. Waring. In this set the alumina is as remarkably low as it was high in the other series. Taken together the two sets, which cover much the same slates, are excellent examples of what may

be expected when difficult analyses are turned over to ordinary chemical laboratories. The localities are as follows:

- 1, 4. Red slate, Southwestern Slate Company.
2. Green slate, Southwestern Slate Company.
- 3, 5. Black slate, Harrington property.
- 6, 7. Green slate, Jones property.
- 8, 9. Red slate, Jones property.
10. Buff slate, Baker property.
11. Green slate, Southwestern Slate Company.
12. Red slate, Southwestern Slate Company.
- 13, 14. Red slate, State House Cove.
15. Green slate, State House Cove.
- 16, 17. Black slate, Crooked Creek.

TABLE 60. — ANALYSES OF SLATES: CALIFORNIA, UTAH.

	1	2	3	4
Silica.....	63.52	47.30	45.15	54.05
Alumina.....	16.34	15.53	16.33	20.95
Iron oxides.....	6.79	8.00	8.42	9.28
Lime.....	0.98	7.83	6.42	0.22
Magnesia.....	2.50	7.86	8.72	0.12
Potash and soda.....	n.d.	3.17	n.d.	n.d.
Water, carbon dioxide.....	4.86	9.92	11.28	3.90

1. Black slate, sedimentary; Eureka Slate Company, Kelsey, El Dorado County, Cal.; sampled by E. C. Eckel; analyzed by W. T. Schaller.
2. Green slate, igneous; same quarry as preceding; analysis quoted by company.
3. Green slate, igneous; same quarry as preceding; sampled by E. C. Eckel; analyzed by W. T. Schaller.
4. Purple slate, near Provo, Utah; sampled by E. C. Eckel; analyzed by W. T. Schaller.

TABLE 61. — ANALYSES OF EUROPEAN ROOFING SLATES.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Silica (SiO ₂).....	55.06	58.30	50.88	55.8	59.3	60.50	60.68	61.43	61.57	65.63	48.60	59.35	67.56
Alumina (Al ₂ O ₃).....	22.55	21.89	14.12	25.7	17.5	19.70	21.20	19.10	19.22	20.20	23.50	13.56	12.23
Ferric oxide (Fe ₂ O ₃)...	1.97	7.05	.....	0.3	2.3	7.83	5.68	4.81	6.63	2.72	11.30	1.10	2.87
Ferrous oxide (FeO)...	5.96	2.57	9.96	9.5	3.8	.....	0.46	3.12	1.20	0.85	.....	4.75	6.99
Lime (CaO).....	1.30	0.39	8.72	4.4	5.0	1.12	1.71	0.31	0.22	0.19	.....	5.20	0.27
Magnesia (MgO).....	2.92	1.09	8.67	.....	tr.	2.20	0.88	2.29	0.93	0.71	1.60	3.60	3.03
Soda (Na ₂ O).....	2.17	1.18	.....	.....	.....	2.20	2.09	0.83	3.63	3.81	} 4.70	1.48	1.28
Potash (K ₂ O).....	3.82	2.45	0.88	.....	.....	3.18	3.64	3.24	.....	.....		11.77	1.76
Carbon dioxide (CO ₂)...	.....	6.47	.....	3.2	2.4	.....	.....	.....	.....	.....	.....	4.45	.....
Water.....	4.35	4.61	.....	0.2	6.0	3.30	2.88	3.52	3.25	3.17	7.60	3.41	1.00

1. Mohradorf, Austria; Nikolic, analyst; 19th Ann. Rep. U. S. Geol. Sur., pt. 3, p. 261.
2. Delabole, Cornwall, England; J. A. Phillips, analyst; 19th Ann. Rep. U. S. Geol. Sur., pt. 3, p. 261.
3. Lake District, Westmoreland, England; G. Vogt, analyst; Jour. Inst. British Architects, Vol. 3, p. 196.
- 4, 5. Lake district, Westmoreland, England; Lock, analyst; Economic Mining, p. 367.
6. Average, Wales; Hull, "Building Stones," p. 291.
7. Llanberis, Wales; 19th Ann. Rep. U. S. Geol. Sur., pt. 3, p. 261.
8. Rimogne, Ardennes, France; Klement, analyst; 19th Ann. Rep. U. S. Geol. Sur., pt. 3, p. 261.
- 9, 10. Fumay, Ardennes, France; A. Renard, analyst; 19th Ann. Rep. U. S. Geol. Sur., pt. 3, p. 261.
11. Angers, France; D'Aubisson, analyst.
12. Frankenberg, Prussia; A. von Groddeck, analyst; 19th Ann. Rep. U. S. Geol. Sur., pt. 3, p. 261.
13. Westphalia, Prussia; H. von Deeken, analyst; 19th Ann. Rep. U. S. Geol. Sur., pt. 3, p. 261.

COLOR, TEXTURE AND STRUCTURE.

Color of Slates. — Slates from various districts, and in some cases even from different parts of the same quarry, show very marked differences in color. The commonest colors are various shades of gray and bluish gray. Black is probably the next most abundant color, followed in turn by reds of various shades. Greens are less common, especially the purer and clearer greens, though grayish green is not rare. Purple is perhaps the scarcest of the colors in which slate is found. Yellow, brown and buff slates occur, but these colors are invariably due to weathering and though showing at the surface do not occur in the merchantable slate.

In almost all cases, the colors shown by slates are due to the amount and condition of two of the constituents of the slate — organic matter and iron oxides. It may be fairly assumed that the normal or average slate color is some shade of gray. If the slate contains considerable finely divided carbonaceous matter, it will probably show a glossy black color on its cleavage surfaces. If it is high in ferric iron, it will probably be a red or purple slate. If the iron is in the ferrous form, the slate will normally be green, if fairly free from organic matter; and black if organic carbon is present in addition to the ferrous iron.

Economic Importance of Color. — The color of slate is of importance industrially in so far as it affects the physical properties, the permanence and the salability of the product.

So far as strength is concerned, there is little to choose between the various colors. The glossy black slates are, on the average, apt to be somewhat finer grained, somewhat softer, and considerably more smooth and even grained than those of any other color. The gray slates, on the other hand, usually are at the other extreme of the series in all of these respects; while the red and green slates are intermediate. The properties in which the black slates excel are obviously those which fit them well for mill stock; while they are negative or actually harmful so far as strength and durability are concerned.

In regard to permanence of color throughout long exposure to the weather, which is a matter of importance in the selection of roofing slates, slates may be either practically permanent in tint, they may fade evenly and slightly or they may fade or discolor in uneven patches. Except for the difficulty in matching the tint when a few slates on a roof require replacement, there would be no objection to a moderate and even fading, while of course a slate which changes color in blotches is highly objectionable. So far as original color affects these matters, it may be said that the black and gray slates are commonly either entirely permanent in color, or show but slight changes; that the bluish slates often turn more grayish, while most red slates take on a browner tint. The green slates are the most doubtful always, for while some of them are practically permanent in color, others discolor badly. The change in color of the fading green slates is due, according to Dale and Hillebrand, to the presence of small quantities of unstable iron-lime-magnesia carbonates, in which the ferrous iron gradually oxidizes and hydrates to limonite. The development of discoloring blotches in slate of any tint is generally due either to the same cause, or to the weathering of small grains of iron sulphide (pyrite or marcasite).

The salability of slate is largely influenced by color. As the entire slate trade is governed by tradition, it being in this respect perhaps the most archaic of existing industries, it is very difficult to introduce a new slate, and particularly so if its color differs from that to which the particular local market is accustomed. When a new company attempts to do this, its competitors never

have the slightest difficulty in producing a hundred ancient Welshmen who are willing to swear that, in all the years since Wales first rose above the sea, no one has appeared mad enough to even suggest using a slate of that particular tint for roofing purposes. It is only recently that the slate trade has thought of submitting such matters to laboratory tests, in place of relying on the traditional lore of the bards.

There is a very definite advantage to a slate company arising from the control of two or more colors of slate, whether these are taken from the same quarry or from entirely different districts. Architects usually specify color as well as grade, and a company which can supply only one good color or type of slate must necessarily lose a good deal of desirable business. A good example of the advantage of controlling two well-contrasting colors is afforded by a western company whose quarry is in a glossy black slate, but with a few narrow bands of green slate. The latter is marketed for lettering and ornamental work on the black slate background, and the idea has taken very satisfactorily. In the eastern states the slate industry seems to be on the verge of developing on a larger scale than heretofore, and doubtless this development will ultimately take the form of large companies each owning a number of quarries in different districts, so that each can supply slate of any specified grade and color.

Cleavage. — The most striking difference between slates and shales lies in the fact that while shales ordinarily break into irregular blocks, slates show a very perfect cleavage in one plane, though breaking irregularly in all other directions. This slaty cleavage is a phenomenon closely akin to the gneissoid lamination shown by many granites, and discussed on an earlier page. In neither case is the cleavage nor banding necessarily parallel to earlier bedding planes. In slates, for example, it is occasionally found that the cleavage plane intersects the original bedding plane at a high angle; and indeed most books dealing with the subject allow it to be supposed that such discordance between cleavage and bedding is the normal condition. The writer's experience, however, is that in by far the majority of cases the cleavage of our commercial slates is either absolutely parallel to the original bedding, or else diverges from it at only a small angle.

When the bedding plane and plane of slaty cleavage coincide exactly, so that the slate splits most readily along its original bedding planes, the split surface will usually be rough and uneven, so that such a slate does not give satisfactory roofing material but must be used as mill stock.

Surface weathering decreases the durability and the splitting properties of slates. For this reason it is difficult to decide as to the value of a slate property from surface exposures only. It may be taken as a general rule that the deeper from the surface, the better the slates will be as to soundness, strength, color, cleavage and size of blocks. This rule is not invariable, however, and it cannot be carried too far. Slate from an opening 50 feet below the surface will almost always be superior in every way to surface slate; but slate from a 100-foot hole should not be expected to be much if any better than that from a 50-foot hole.

PHYSICAL PROPERTIES AND TESTING.

Desirable Properties of Slates. — Slate may be used for two general purposes — mill stock and roofing slate; and the properties which are desirable for one use are not necessarily important for the other, a fact which is often overlooked.

For mill stock a slate should preferably be fine and even-grained, soft rather than hard and reasonably uniform in color. For the sake of the dressing machinery it should be free from grains of quartz, pyrite or other hard minerals. Its color and chemical composition are of no particular importance for such use.

For roofing slate durability and strength are of value. A roofing slate should be practically permanent in color, even after exposure to damp and acid atmospheres; it should stand punching cleanly, and should be strong and tough enough to stand rough handling during shipment, laying and use. Pyrite, iron carbonate and other unstable minerals are highly undesirable.

It will be seen from the above summary that no one is particularly interested in the compressive strength of roofing slate — and still this is occasionally determined and recorded with proper solemnity. The specific gravity is of interest chiefly because a dense heavy slate may be expected, other things being equal, to be more durable than one of more porous nature.

TABLE 62. — SPECIFIC GRAVITY OF ROOFING SLATES.

Quarry.	Location.	Tested by	Specific gravity.
Eureka quarries.....	Poultney, Vt.....	W. F. Hillebrand..	2.795
Eureka quarries.....	Poultney, Vt.....	W. F. Hillebrand..	2.8053
Hughes quarry.....	Pawlet, Vt.....	W. F. Hillebrand..	2.791
Auld & Conger.....	Wells, Vt.....	W. F. Hillebrand..	2.7627
McCarty quarry.....	South Poultney, Vt.....	W. F. Hillebrand..	2.8064
American Black Slate Co.....	Benson, Vt.....	W. F. Hillebrand..	2.7748
American Black Slate Co.....	Benson, Vt.....	W. C. Day.....	2.764
American Black Slate Co.....	Benson, Vt.....	W. C. Day.....	2.786
National Red Slate Co.....	Raceville, Washington Co., N. Y.....	.....	2.7839
National Red Slate Co.....	Raceville, Washington Co., N. Y.....	.....	2.7171
Empire Red Slate Co.....	Granville, Washington Co., N. Y.....	.....	2.8085
	Peach Bottom, Pa.-Md.*.....	M. Merriman.....	2.894
	Chapman, Pa.....	E. S. Bailey.....	2.79
	Albion, Pa.*.....	M. Merriman.....	2.775
	Bangor, Pa.*.....	M. Merriman.....	2.780
	Westmoreland, England.....	G. Vogt.....	2.77
	Delabole, Cornwall, England.....	J. A. Phillips.....	2.81
	Mohradorf, Austria, Silesia.....	Nikolic.....	2.78
	Lake District, England.....	.....	{ 2.775 2.8

* Average of 12 specimens.

TABLE 63. — COMPARATIVE TESTS OF ROOFING SLATES.
(MERRIMAN.)

Locality.	Color.	Transverse strength — modulus of rupture in pounds per square inch.	Toughness — ultimate deflection in inches on supports 22 inches apart.	Density — specific gravity.	Softness — amount in grams abraded by 50 turns of a small grindstone.	Porosity — per cent of water absorbed in 24 hours.	Corrodibility — per cent of weight lost in acid solution in 63 hours.
<i>Maine district:</i>							
Merrill Slate Co., Brownville.	Gray.....	9,880	0.200	2.798	0.265	0.148	0.305
Monson Consol. Slate Co., Monson.....	Gray.....	9,130	0.205	2.794	0.256	0.188	0.286
<i>New York-Vermont district:</i>							
Matthews Slate Co., Granville	Green.....	8,050	0.190	2.783	0.226	0.374	0.379
Matthews Slate Co., Granville	Red.....	9,220	0.232	2.848	0.148	0.243	0.373
Vermont Green Slate Co.....	Green.....	6,410	0.225	2.771	0.341	0.231	0.295
Rising & Nelson.....	Green.....	7,250	0.207	2.736	0.190	0.325	0.768
<i>Lehigh district: Penn.-N. J.</i>							
Chapman Slate Co., Chapman, Pa.....	Dark gray	9,460	0.212	2.764	0.208	0.231	0.383
Albion quarry, Pan Argyle.....	.....	7,150	0.270	2.775	.....	0.238	0.547
Old Bangor quarry, Bangor...	.....	9,810	0.312	2.780	.....	0.145	0.446
<i>Peachbottom district: Penn.-Md.</i>							
Locality not stated.....	.....	11,260	0.293	2.894	.....	0.224	0.226
<i>Virginia district:</i>							
Williams Slate Co., Arvonvia ..	Dark gray	9,040	0.227	2.781	0.060	0.143	0.394
Pitts quarry, Arvonvia.....	Dark gray	9,850	0.225	2.791	0.108	0.216	0.323

List of References on Properties and Testing of Slates. — The following brief list will serve to direct the reader's attention to

the only papers on this subject which seem to contain matter of serious importance.

- Dale, T. N. Slate deposits and slate industry of the United States. Bul. 275, U. S. Geol. Sur., pp. 45-50, 122-125, on tests of slate.
- Merriman, M. The strength and weathering qualities of roofing slates, Trans. Amer. Soc. Civil Engineers, Vol. XXVII, pp. 331-349. 1892.
- Merriman, M. The strength and weathering qualities of roofing slates, Trans. Am. Soc. C. E., Vol. XXXII, pp. 529-543. 1894.
- Merriman, M. Recent tests of various roofing slates. Bull. 275, U. S. Geol. Sur., pp. 122-124. 1906.

DISTRIBUTION AND PRODUCTION OF SLATE.

Geologic Distribution of Slates.—The formation of a deposit of roofing slate, as has been explained in previous sections, involves the existence of clayey sediments in an area which undergoes extreme metamorphism. The geologic age of the original clay beds does not enter into the problem, except that as a general thing the older beds, having a longer history, have had more chance of being metamorphosed. But unless the inquiry be limited to particular geographic or geologic areas, it is not possible to say in advance that the rocks of any particular geologic period are likely to be slate-bearing.

If, however, the question is so limited to particular areas, geologic history will afford some guidance in the search for slate. In the eastern and southeastern United States, for example, all of the known slate deposits are of either Cambrian or Ordovician age; because in the New England and Appalachian region these rocks were involved in the general metamorphism of the region while the Carboniferous and newer rocks were deposited after the bulk of the metamorphic action had ceased in this area. In the western states, on the other hand, where earth movements of great intensity took place much later in geologic history, we find clayey sediments of Jurassic age converted into slate. The slates of the Lake Superior region, in Michigan and Minnesota, are even older than those of the eastern states, for all of the Lake Superior slates date back to pre-Cambrian time.

Geographic Distribution of Slates.—The geographic distribution of slate deposits in the United States, as may be inferred from the preceding section, is fixed by the geologic history of the various portions of the country. Wherever clayey sediments have existed in any region, during a period when the region in

question was subjected to metamorphic action, we may fairly expect to find that in part of their extent at least these clayey sediments have been converted into slates. Since the physical results of earth movements are most extreme in cases where relatively soft rocks are pressed against or between masses of harder rocks, it is natural enough to find that slaty cleavage is best developed under these conditions. Accordingly, practically all of the important slate deposits occur in areas where clayey sediments had been deposited along an older granite shore line; and where these sediments were later pressed against the less yielding granites and gneisses. In New England and the Appalachian region the clayey sediments were deposited during the Cambrian and Ordovician periods along a shore line of pre-Cambrian gneisses and schists; and during subsequent earth movements many of the sediments were turned into slates. In the Lake Superior, Ozark and Rocky Mountain regions a similar sequence of events took place, though not at the same periods in the earth's history. The geologic history of slate deposits therefore limits their possible geographic distribution, so that we find all of the important slate deposits of the world fringing older igneous masses.

Chief American Quarry Districts. — For local details concerning the various slate deposits of the United States, reference should be made to the official report by Dale and others noted in the bibliography on page 125 of this volume. In the present place only brief mention will be made of the more important American slate districts. The map accompanying Dale's report shows the location of the present producing districts, as well as of a number of the more promising prospects.

For a reason suggested in the previous section, the American slate districts follow in their general distribution the granite areas. We have, therefore:

1. Extensive slate deposits along the Appalachian belt, from New England to Alabama. In this region the slates are all of Cambrian or Ordovician age, and represent original clayey beds which were violently stressed against and between the older and more resistant masses of pre-Cambrian granites, gneisses and schists. The principal producing areas within this extensive general belt are the isolated Monson district of Maine; the important area along the New York-Vermont border; the Lehigh

region of Pennsylvania-New Jersey; the Peachbottom region of Pennsylvania-Maryland; the separated Esmont, Arvonnia and Snowden areas of Virginia; and less well-developed areas in eastern Tennessee and northwest Georgia.

2. Extensive but little developed slate deposits bordering the massive rocks of the Lake Superior region, in Minnesota and Michigan.

3. Separated small areas in Texas and Arkansas, fringing regions of great local earth movement.

4. Scattered and mostly undeveloped areas along the Rocky Mountain and other western mountain chains; the only developed district being in central California.

Chief Foreign Districts.—British slates are obtained principally from three districts: North Wales, Cornwall and Westmoreland. The Welsh slates are green, purple, black and pale gray in color; are quarried largely near Llanberris, Penrhyn, Ffestiniog, Llangollen, Carnarvon and Bangor; and are shipped from Portmadoc and other ports. The Cornish slates are gray to blue in color, are quarried at Delabole and shipped from Tintagel and Boscastle. The slates of the Lake district of Westmoreland are light blue to light green in color, are quarried near Kendal and are rarely exported. Other districts in England, as well as in Ireland and Scotland, produce smaller amounts of slate.

The principal slate deposits of France are located in two quite distinct districts, one being near Angers in the Department of Maine et Loire and the other in the Ardennes. The slates quarried in the first district, at Angers and Poligny, are dark blue in color and are shipped from Nantes. The Ardennes slates are quarried at Rimogne, Fumay and Deville.

Dressing of Roofing Slates.—Roofing slates pass through three operations—blockmaking, splitting and dressing—before they are ready for the market. At times they are further subjected to punching or to counter-sinking, according to the requirements of the purchaser. All of these operations were formerly carried on by hand, and at most small quarries and some large ones hand labor is still depended on for most of the work. Some of the operations can, however, be done more economically by machinery.

The slate is hoisted from the quarry in slabs which average perhaps 6 feet by 3 feet by $1\frac{1}{2}$ feet. When hand dressing is



Fig. 17. — Slate dressing: the dressing sheds.



Fig. 18. — Slate dressing: the beginning of sculpting.

depended on, these slabs are loaded on a tram car and pushed to the dressing sheds, a series of little sheds or cabins each occupied by a dressing gang. A dressing gang includes three men — a blockmaker, a splitter and a dresser. Ordinarily each gang takes contracts from the company at a fixed price per square of finished slate, the receipts being divided by the three members of the gang in fairly equal proportions, though the dresser or



Fig. 19. — Slate dressing: sculping.

trimmer usually gets a little less than the other two. The work is divided and carried on as follows: The blockmaker takes the large slabs or blocks above noted and cuts them into manageable slabs about 2 feet by $1\frac{1}{2}$ feet in size and 2 inches thick. This is done with the chisel. In making the cut *across* the grain the operation is called "sculping," and is shown in Figs. 18 and 19. A V-shaped notch is first cut in one side of the slab with the gouge (Fig. 18), after which the splitting chisel is held with edge vertical in this notch and struck with the hammer (Fig. 19). The slab is now passed on to the splitter, whose special tool

is the thin splitting chisel (Fig. 20), 10 to 15 inches long, and with an edge 2 to $3\frac{1}{2}$ broad. One or more of these are driven into the slate, along some cleavage plane, with the maul, and are then worked backward and forward by hand until the slate splits. The splitting is continued until the slates are reduced to the proper thickness, which may be from one-eighth to one-fourth inch. The slates, now of proper and uniform thickness,



Fig. 20. — Slate dressing: splitting.

but of irregular shapes, are given to the dresser or trimmer, who formerly trimmed them to size with a knife. At present hand- or foot-power dressing machines are employed everywhere — the general design being a long knife, set vertically and hinged at one end, while the other end is alternately raised and lowered by hand or by a treadle.

At a large Pennsylvania quarry the slate blocks were delivered by the company in front of the dressing sheds, and tools were furnished and sharpened at company expense, while the dressing gang received the following prices per square of finished slate:

No. 1 quality	\$1.10 per square
Intermediate quality	1.00 per square
No. 2 quality . . . . .	.90 per square

It has been noted that machine work is now employed for some of these operations. Splitting is still done by hand labor, as mechanical splitters have rarely given good results. The blocks, however, are usually given at least one sawed edge before being handed to the splitter, this being done on a sawing table with vertical saw, such as is used in preparing mill stock.

Measurement of Roofing Slates.—Two different units of measurement are employed in the slate trade, the *square* and the *mille*, the former being used at all American quarries, while the latter is found in French and English markets.

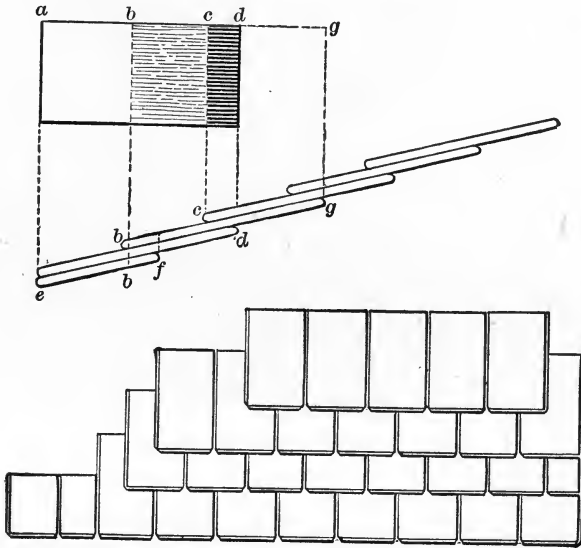


Fig. 21.—Laying of roofing slate.

The *square* is the number of slates of a given size necessary to cover 100 square feet of roof, with a given lap. Let b equal breadth of slates, d equal length of slates and l equal lap. Then the number of slates to the square will equal $14,400 = \frac{bd - bl}{2}$ or $\frac{28,800}{bd - bl}$. This formula may be used for computing the number of

slates to the square for any given size and lap; but for convenience table 64 is inserted, which gives this information for the ordinary sizes of slates with a three-inch lap.

TABLE 64. — NUMBER OF SLATES PER SQUARE.

Size of slate.	Number of slates per square.	Size of slate.	Number of slates per square.	Size of slate.	Number of slates per square.
7 × 3	2400	10 × 7	588	16 × 10	222
7 × 4	1800	10 × 8	515	16 × 12	185
7 × 5	1440	12 × 6	534	18 × 9	214
8 × 4	1440	12 × 7	458	18 × 10	192
8 × 5	1152	12 × 8	400	18 × 11	175
8 × 6	960	12 × 9	356	18 × 12	160
9 × 4	1200	12 × 10	320	20 × 10	170
9 × 5	960	14 × 7	374	20 × 11	154
9 × 6	800	14 × 8	328	20 × 12	142
9 × 7	686	14 × 9	291	22 × 11	138
9 × 8	600	14 × 10	262	22 × 12	127
10 × 4	1039	14 × 12	219	24 × 12	115
10 × 5	822	16 × 8	277	24 × 14	98
10 × 6	685	16 × 9	247		

The *mille*, which is a unit much used in Europe, is nominally 1200 slates of any given size. As slates are shipped at the purchaser's risk, however, 60 slates are added to cover breakage, so that the actual mille contains 1260 slates. The number of squares in a mille will of course vary according to the size of the slate.

In the English and Welsh slate trades certain fanciful names have long been used for the different sizes of roofing slates. These names are not always uniformly applied in the different British slate districts, and of late years they seem to be falling somewhat into disuse. But as they are still frequently met with both in export business and in trade literature the following table* has been inserted in explanation of the terms.

* Notes on Building Construction, Part III, p. 29.

NAMES AND SIZES OF BRITISH SLATES.

Sold by weight.	Size.	Sold by size.	Size.
	Inches.		Inches.
Queens.....	36×24	Ladies, large.....	16× 8
Rags.....	36×24	Ladies, small.....	14×12
Imperials.....	30×24	Ladies, small.....	14×10
		Ladies, small.....	14× 8
Sold by size.		Ladies, small.....	14× 7
Empresses.....	26×15	Doubles.....	13×10
Princesses.....	24×14	Doubles.....	13× 7
Duchesses.....	24×12	Singles.....	12× 8
Marchionesses.....	22×12	Singles.....	12× 6
Marchionesses, small.....	22×11	Singles.....	11× 6
Countesses.....	20×10	Singles.....	10× 8
Viscountesses.....	18×10	Singles.....	10× 6
Viscountesses, small.....	18× 9	Singles.....	10× 5
Ladies, large.....	16×10		

Thickness. — The thickness of a roofing slate varies usually with the size of the slate, decreasing with its area. In Welsh practice* the following rule is observed:

Size of slate.	Thickness.	
	First quality.	Second quality.
Inches.	Inch.	Inch.
22×11 to 24×12	$\frac{3}{15}$	$\frac{3}{11}$
16× 8 to 20×10	$\frac{1}{6}$	$\frac{1}{4}$
13× 7 to 14×12	$\frac{2}{10}$	$\frac{2}{8}$

Slates are graded according to their smoothness of surface, even thickness, and (in some districts) uniformity of color. Usually two grades will cover the output of any given quarry, but occasionally a third grade is employed.

Roofing slates are always cut so that the longer sides of the slate are in the direction of the grain. This is done not only to secure ease of dressing, but to give additional security for slate roofs. If a slate so cut be broken while on the roof, the fracture will be in the direction of the grain, and the two fragments of the slate will still be held by single nails; while if the slate had been cut in the opposite direction (*i.e.*, longer sides *across* the grain) the lower part of a broken slate would have nothing to hold it on the roof.

* Notes on Building Construction, Part III, p. 28.

Statistics of Slate Production.—The following statistical tables are quoted from the current volume of Mineral Resources United States.

The following table shows the total value of the slate produced in the United States from 1905 to 1909, inclusive:

TABLE 65.—VALUE OF SLATE PRODUCED IN THE UNITED STATES, 1905-1909, BY STATES.

State.	1905	1906.	1907.	1908.	1909.
Arkansas.....	\$10,000	\$5,000	\$8,500	\$2,500	.....
California.....	40,000	80,000	60,000	60,000	*
Georgia.....	7,500	5,000	.....	.....	*
Maine.....	224,254	238,681	236,606	213,707	\$227,882
Maryland.....	151,215	130,969	116,060	102,186	129,538
New Jersey.....	5,360	.....	8,000	.....	*
New York.....	66,646	72,360	83,485	130,619	107,436
Pennsylvania.....	3,491,905	3,522,149	3,855,640	3,902,958	2,892,358
Vermont.....	1,352,541	1,441,330	1,477,259	1,710,491	1,841,589
Virginia.....	146,786	172,857	173,670	194,356	180,775
Other States †.....	.....	.....	.....	.....	61,840
Total.....	5,496,207	5,668,346	6,019,220	6,316,817	5,441,418

* Included in "Other States."

† Includes California, Georgia and New Jersey.

The following table shows the value of slate produced for roofing and for mill stock from 1905 to 1909, inclusive:

TABLE 66.—VALUE OF ROOFING SLATE AND MILL STOCK, 1905-1909.

	Roofing slate.		Value of mill stock.	Total value.
	Number of squares.	Value.		
1905	1,241,227	\$4,574,550	\$921,657	\$5,496,207
1906	1,214,742	4,448,786	1,219,560	5,668,346
1907	1,277,554	4,817,769	1,201,451	6,019,220
1908	1,333,171	5,186,167	1,130,650	6,316,817
1909	1,133,713	4,394,597	1,046,821	5,441,418

The following table shows the average price of roofing slate per square in the entire United States since 1902:

1902.....	\$3.45	1906.....	\$3.66
1903.....	3.88	1907.....	3.77
1904.....	3.78	1908.....	3.89
1905.....	3.69	1909.....	3.87

TABLE 67. QUANTITY AND VALUE OF ROOFING, MILL AND OTHER SLATE PRODUCED IN THE UNITED STATES IN 1908 AND 1909, BY STATES.

1908.

State.	Number of operators.	Roofing slate.			Mill stock.						Other uses; values.	Total value.	
		Number of squares.	Value.	Average price per square.	Manufactured.		Rough.		Total.				
					Quantity.	Value.	Quantity.	Value.	Quantity.	Value.			
													Sq. feet.
Arkansas.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	\$2,500	.....
California.....	1	7,000	\$60,000	\$8.57	.....	.....	.....	.....	.....	.....	.....	60,000	.....
Maine.....	5	20,151	115,682	5.74	.....	.....	.....	.....	.....	.....	.....	213,707	.....
Maryland.....	6	18,521	101,204	5.46	285,299	\$98,025	.....	.....	.....	.....	.....	102,186	.....
New Jersey.....	2	.....	.....	{ 4.05 }	.....	.....	.....	.....	.....	.....	.....	.....	.....
New York.....	11	18,485	130,439	{ 8.10 }	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pennsylvania.....	102	825,078	3,070,906	3.72	2,593,430	435,884	.....	.....	.....	.....	.....	3,902,958	.....
Vermont.....	51	402,258	1,513,580	3.76	707,563	168,441	.....	.....	.....	.....	.....	1,710,491	.....
Virginia.....	7	41,678	194,356	4.66	.....	.....	.....	.....	.....	.....	.....	194,356	.....
Total.....	186	1,333,171	5,186,167	3.89	3,586,292	702,350	.....	.....	.....	.....	.....	337,346	6,316,817

1909.

California.....	1	.....	.....	6.56	.....	.....	.....	.....	.....	.....
Georgia.....	1	.....	.....	5.75	.....	.....	.....	.....	.....	.....
Maine.....	6	18,024	\$101,865	5.65	372,229	\$126,017	372,229	\$126,017	.....	\$227,882
Maryland.....	6	22,563	128,227	5.68	.....	.....	.....	.....	.....	129,538
New Jersey.....	2	.....	.....	4.39	.....	.....	.....	.....	.....	.....
New York.....	8	18,098	106,175	5.70	5,543	1,201	500	6,043	1,261	107,436
Pennsylvania.....	98	626,228	2,281,779	3.64	2,419,905	364,803	969,214	76,661	441,464	2,892,358
Vermont.....	51	397,441	1,533,936	3.86	1,133,257	281,882	212,246	25,465	307,347	1,841,589
Virginia.....	7	40,880	180,775	4.42	.....	.....	.....	.....	.....	180,775
Other States \$.....	.....	10,479	61,840	.....	.....	.....	.....	.....	.....	61,840
Total.....	180	1,133,713	4,394,597	3.87	3,930,934	773,903	1,181,960	102,186	876,089	5,441,418

* Composed of 5,036,147 school slates, valued at \$42,364, and 2,338,886 square feet of blackboard material, valued at \$291,500.

† Included in "Other States."

‡ Composed of 3,650,831 school slates, valued at \$32,319; 1,095,540 square feet of blackboard material, valued at \$130,195, and \$6,601 for slate used for structural and other purposes.

\$ Includes California, Georgia and New Jersey.

EXPORTS.

In comparison with the total output, the value of roofing slate exported from this country in 1909 was very small, being \$209,383; in 1908, \$197,216 was the value of slate exported.

IMPORTS.

Practically no slate is imported into the United States. In 1908 slate valued at \$7227 was imported in the form of mantels, chimney pieces, roofing slate, slabs, etc.; in 1909, the importations were valued at \$7872, and included the same articles.

List of References on Slate Deposits. — In the reference list following, only such American reports are listed as have appeared after the publication of Dale's general report on the slate deposits of the United States.

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Anon. The Welsh slate quarries. Eng. and Min. Jour., Dec. 31, 1898.

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H. J. W. Thuringian quarries. *Stone*, September, 1896.

Kruger, R. Die naturlichen Gesteine. Leipzig, 1889. pp. 123-136, slates.

Watrin, N. Les ardoisieres des Ardennes. Charleville, 1898.

Anon. Stones from Norway and Sweden. *Stone*, April, 1896.

CHAPTER VIII.

SANDSTONES.

Scope of Term Sandstone. — The term *sandstone* is here used in a general way to include all the sedimentary rocks which have originated through the consolidation of beds of sand or gravel, as well as the scarcer beds of tuff. In this sense the sandstones are purely mechanical deposits, always of immediate sedimentary origin, and are predominantly siliceous in composition. As noted in a later paragraph, the term sandstone as here used covers not only the *sandstones* proper, but also the *conglomerates* and *breccias*.

ORIGIN AND COMPOSITION.

Origin of Sandstones. — The sandstones have originated through the gradual consolidation of beds of sand and gravel, this consolidation being primarily due to the pressure of overlying beds exerted during long periods of time. Such pressure, acting alone, would probably have been insufficient to secure any high degree of consolidation. In most cases, however, a cementing material of some sort was either originally present in the beds of sand, or was introduced at some later period, so that the present degree of consolidation is due to the combined effects of pressure and cementing material. In some cases, the cementing material was clay originally deposited with the sand; but in the majority of instances the cementation was effected by the infiltration of waters containing dissolved silica, lime carbonate, or iron oxide. Whether these mineral-bearing waters permeated the sand bed before it was covered by other deposits, or whether they were subsequently introduced into the rock, the final effect was the same, for the dissolved substances were ultimately precipitated around and between the grains of sand, so as to cement them together.

The result of this method of origin is that, on examining any sandstone or conglomerate, two different types of constituents

can usually be determined. First, there are a multitude of grains or pebbles of sand, gravel, etc. Second, surrounding and cementing these grains together is a matrix of clay, of clear silica, of iron oxide, or of lime carbonate, as the case may be.

Origin of Tuffs. — Owing to their considerable extent and importance in the western United States, one particular class of sandstones deserves separate mention here, since both in origin and in composition it differs from the normal type of sandstone. The class in question is that which includes the *tuffs*, which are beds of consolidated volcanic ash. When volcanic ash falls upon a land area, it rarely becomes sufficiently consolidated to be of structural importance. If it falls into lake basins or other bodies of water, or if it is carried by running water into such basins without being mixed with much other material, the water-deposited beds of ash may later become almost as hard as other sandstones.

Chemical Composition of Sandstones. — The sandstones vary considerably in chemical composition, the variation being due not only to differences in the character of the original grains, but to differences in the composition of the cementing material.

TABLE 69. — AVERAGE ANALYSES OF AMERICAN SANDSTONES.

	A.	B.
Silica (SiO_2).....	78.66	84.86
Alumina (Al_2O_3) *.....	5.03	6.37
Ferric oxide (Fe_2O_3).....	1.08	1.39
Ferrous oxide (FeO).....	0.30	0.84
Lime (CaO).....	5.52	1.05
Magnesia (MgO).....	1.17	0.52
Soda (Na_2O).....	0.45	0.76
Potash (K_2O).....	1.32	1.16
Phosphorus pentoxide (P_2O_5).....	0.08	0.06
Sulphur trioxide (SO_3).....	0.07	0.09
Carbon dioxide (CO_2).....	5.04	1.01
Combined water †.....	1.33	1.47
Moisture.....	0.31	0.27

* Including titanic oxide (TiO_2).

† Including organic matter.

- A. Composite analysis of 253 samples of American sandstones, use not stated. H. N. Stokes, analyst.
 B. Composite analysis of 371 samples of American sandstones used for building purposes. H. N. Stokes, analyst.

A sandstone composed of quartz grains, cemented by quartz, would naturally show on analysis a very high silica percentage. On the other hand, a sandstone composed of grains of quartz, feldspar, mica, etc., cemented together by iron oxide or lime carbonate, might not show over 75 or 80 per cent of silica.

It is difficult, from a series of analyses such as is given later, to secure any very definite idea of the average composition of the group as a whole. This is accomplished, however, by Table 69, immediately preceding, which gives average results of considerable interest.

Value of Chemical Work on Sandstones. — The value, from the engineer's point of view, of a chemical analysis of any particular sandstone which may be under investigation at the moment, will depend upon a number of factors.

The writer's opinion on this subject may be summarized as follows:

(a) If a specimen of the stone is available for examination, with or without the use of a hand lens, the results reported by the analyst can usually be interpreted with considerable confidence and accuracy. In this case, the chemical analysis can be made to afford information of distinct value to the engineer, for ocular examination of the stone will usually decide which of the elements reported exists in the component grains, and which in the cementing material.

(b) If no specimen of the stone is available, and it happens that some sort of judgment must be given on the basis of the chemical analysis alone, the case is far less satisfactory, but still not entirely hopeless. Under these circumstances, the engineer must look with suspicion on any lime, magnesia, alkalies, or carbon dioxide found in the report of the analysis; and must remember that, *other things being equal*, the percentage of silica, or at times of silica plus alumina and iron, is a rough but fairly trustworthy index to the structural value and probable durability of the stone.

The Interpretation of the Chemical Analysis. — A complete analysis of a sandstone, or, to be more accurate, an analysis complete enough for all practical purposes, will result in determinations of the following constituents: Silica (SiO_2), alumina (Al_2O_3), ferrous oxide (FeO), ferric oxide (Fe_2O_3), lime (CaO), magnesia (MgO), potash (K_2O), soda (Na_2O), carbon dioxide

(CO₂), combined water, and moisture. In some cases it may be advisable to determine also sulphur and carbon or organic matter.

If the analysis be made by an ordinary commercial chemist it may be safely assumed that his results on potash and soda are absolutely worthless, and that his silica and alumina were not completely separated. Fortunately, however, as will be seen later, these errors of poor analysts are not so harmful as they might appear, owing to the curious fact that if a deleterious constituent be reported too low, some other deleterious constituent will be reported too high; while the beneficial constituents of the sandstone tend to balance themselves in similar manner.

As a rule it will be safe to assume, in trying to interpret a sandstone analysis, that the bulk of the silica reported is represented by the sand grains; and that the other constituents reported — iron, lime, magnesia, etc. — are probably from the cementing material. In any given case, examination of a hand specimen of the rock will give a sufficiently accurate idea of the truth of these assumptions.

Under ordinary conditions, therefore, high percentages of lime, magnesia, and alkalis are characteristic of the less durable sandstones; while high silica is characteristic of the better class of stones. The type exemplified by the bluestone of New York and Pennsylvania must, however, be borne in mind, for in this type the silica is not high, while alumina is present in notable quantity, the cementing material being clayey in composition.

TABLE 70. — ANALYSES OF AMERICAN SANDSTONES.

State.	Location.	Silica.	Alumina.	Iron oxide.	Lime.	Magnesia.	Alkalies.	Carbon dioxide.	Water.
Alabama	Winston Co.....	91.31	2.50	3.80	tr.	.....	.....	.....	0.71
Arizona	Flagstaff.....	79.19	1.30	2.45	7.76	0.23	.....	5.77	3.26
	".....	82.23	.....	2.07	8.19	.....	.....	.....	0.13
California	Redding.....	86.79	6.30	.....	0.51	.....	.....	.....	6.20
	Colusa.....	85.99	4.82	4.49	1.05	0.76	.....	0.82	2.07
Colorado	Glencoe.....	95.85	2.64	.....	0.81	0.08	.....	.....	0.45
	Armejo.....	80.55	10.58	.....	0.73	0.38	.....	.....	3.27
	Boulder.....	95.37	.....	2.40	0.92	0.50	.....	0.55	.....
	Trinidad.....	75.23	16.28	.....	1.63	0.92	.....	.....	3.24
	Oak Creek.....	72.58	15.42	.....	1.48	1.48	.....	.....	2.76
Connecticut	Cromwell.....	70.84	13.15	2.48	3.09	tr.	8.73	1.01	.....
Illinois	Rock Island.....	94.86	2.91	tr.	0.80	0.10	0.84	0.73	.....
	Elco.....	92.50	6.25	0.70	.....	.....	.....	.....	.....
Indiana	Riverside.....	93.16	1.60	2.69	0.13	.....	.....	.....	.....
	".....	91.66	0.60	6.44	0.05	.....	.....	0.04	.....
	Portland.....	91.18	2.14	1.12	0.48	1.41	.....	.....	3.29
	Mansfield.....	92.16	.....	6.29	0.05	.....	0.09	.....	.....
	St. Anthony.....	88.41	0.63	8.40	0.13	.....	.....	0.10	.....
	Bloomfield.....	85.29	0.19	11.23	0.06	.....	.....	0.05	.....
	Greenhill.....	98.73	0.28	0.36	0.03	.....	.....	0.02	.....
	Hillsboro.....	91.65	0.56	6.60	0.12	.....	.....	0.10	.....
	Judson.....	93.21	0.51	4.91	0.12	.....	.....	0.10	.....
	Williamsport.....	98.57	0.05	0.65	0.02	.....	.....	0.02	.....
	Cannelton.....	96.18	0.54	1.56	0.15	.....	.....	.....	.....

TABLE 70.—ANALYSES OF AMERICAN SANDSTONES. — *Continued.*

State.	Location.	Silica.	Alumina.	Iron oxide.	Lime.	Magnesia.	Alkalies.	Carbon dioxide.	Water.
Kansas	Valley Falls,	94.35	2.35		0.64	0.49		1.02	
	" "	97.71	1.31		0.11	0.26		0.38	
	Redfield,	77.32	3.00						
Kentucky	Farmer's Station,	93.13	1.19	2.34	0.32	0.12		0.39	2.51
	Langford,	91.08	4.92		1.19				2.36
Maryland	Cumberland,	98.00	0.65	0.15	0.40	0.21	tr.		0.50
	" "	98.35		0.42					
	Hancock,	76.43	17.78		0.84	0.92			2.79
	Monterey,	99.26	0.61	0.02	0.11				
	" "	99.56	0.34	0.20	0.81				
	" "	99.40	0.47	0.03	0.10				
	" "	97.55	2.44	tr.	0.01				
Massachusetts	East Longmeadow,	88.89	5.95	1.79	0.27		0.86		1.83
	" "	81.38	9.44	3.54	0.76	0.28			4.49
	" "	79.38	8.75	2.43	2.57		4.08		2.79
Michigan	L'Anse,	78.55	14.21	5.54	0.42	tr.			
	Stony Point,	84.57	5.90	6.48		0.68			1.92
	Portage,	94.73	0.36	2.64	0.39	0.36		0.69	
Minnesota	Kettle River,	97.10	2.20		0.60	0.10			
	Hinckley,	98.69	1.06	tr.	0.42	0.01	0.17		
	Pipestone,	84.52	12.33	2.12	0.31		0.45		2.31
	Fort Snelling,	97.67	1.31	0.55	0.41	0.21	0.17		
	Fond du Lac,	78.24	10.88	3.83	0.95	1.60	1.73		
	Dresbach,	81.47	8.90		1.90	0.50	4.59		
	Jordan,	81.19	10.44		0.56	0.40	4.26		
	" "								

TABLE 70. — ANALYSES OF AMERICAN SANDSTONES. — Continued.

State.	Location.	Silica.	Alumina.	Iron oxide.	Lime.	Magnesia.	Alkalies.	Carbon dioxide.	Water.
Mississippi	Starr.....	91.98	0.78	tr.	.....	.....	.....	.....	.....
Michigan	Marquette.....	77.18	9.69	3.20	0.26	1.48	4.85	.....	2.90
	Portage.....	90.17	4.23	3.16	.....	0.29	.....	.....	1.01
	".....	82.60	8.32	0.28	0.55	0.18	6.49	.....	0.99
New Jersey	Wilburtha.....	93.55	4.00	.....	0.40	0.18	0.30	.....	0.12
	Avondale.....	82.05	5.27	2.71	3.35	0.76	0.80	4.40	0.71
	".....	82.16	3.12	2.41	5.10	0.42	1.10	5.03	0.62
	Centre Bridge.....	96.20	1.58	1.37	0.15	0.36	.....	.....	1.15
	Milford.....	79.25	7.49	3.78	1.86	.....	1.12	1.46	3.16
	Washington Valley.....	88.45	3.92	3.03	0.36	0.12	0.88	.....	1.80
	Wilburtha.....	93.60	1.59	3.30	.....	.....	0.35	.....	1.20
New York	Summit.....	76.82	12.52	4.50	0.21	1.10	.....	1.10	.....
	Oxford.....	77.56	10.65	4.59	0.34	1.22	3.05	.....	1.93
	Rock Glen.....	76.50	14.75	6.35	.....	.....	.....	.....	2.00
North Carolina	Carthage.....	79.63	7.16	4.16	0.92	2.63	.....	.....	4.66
	Sanford.....	81.59	10.81	4.38	1.02	0.33	1.08	.....	0.79
	Moore Co.....	84.97	10.31	1.41	1.05	0.79	0.24	.....	1.15
	Wadesboro.....	69.28	13.84	.....	.....	0.02	6.43	.....	1.69
	Sanford.....	82.58	8.95	3.95	1.18	0.81	0.83	.....	1.68
Ohio	Amherst.....	97.00	.....	1.00	1.15	.....	0.64	.....	0.21
	Berea.....	92.91	3.78	0.91	0.31	tr.	0.95	.....	1.19
	".....	96.90	.....	1.68	0.55	.....	0.55	.....	0.32
	".....	84.40	7.49	3.87	0.74	2.11	0.80	.....	.....
	Berlin.....	91.25	6.30	.....	0.31	0.59	.....	0.87	.....

TABLE 70. — ANALYSES OF AMERICAN SANDSTONES. — *Continued.*

State.	Location.	Silica.	Alumina.	Iron oxide.	Lime.	Magnesia.	Alkalies.	Carbon dioxide.	Water.
Ohio	Buena Vista.....	88.27	9.09	tr.	0.28	tr.	.....	.....	2.51
	Cleveland.....	91.67	6.92	tr.	1.00	0.34	.....	.....	1.17
	Columbia.....	96.50	.....	.....	.....	.....	0.50	.....	2.00
	Euclid.....	95.00	2.50	1.00	.....	.....	.....	.....	1.50
	Freepot.....	95.17	0.73	2.53	0.36	tr.	.....	.....	1.17
	Grafton.....	87.66	1.72	3.52	0.17	0.20	.....	.....	2.03
	Hillsboro.....	94.10	3.60	.....	0.73	0.19	.....	0.77	.....
	Killbuck.....	98.15	0.97	.....	.....	.....	.....	.....	.....
	Lancaster.....	96.82	0.51	0.67	0.04	0.01	.....	.....	1.28
	".....	97.76	0.73	0.51	0.12	.....	.....	.....	0.51
	Massillon.....	97.36	2.28	tr.	0.05	0.08	.....	.....	.....
	Portsmouth.....	98.31	.....	0.61	tr.	tr.	.....	.....	1.08
	".....	97.20	.....	1.04	0.36	tr.	.....	.....	1.46
	Sherrodsville.....	95.83	.....	1.65	0.77	tr.	tr.	.....	1.95
	Warren.....	93.34	4.41	1.65	.....	.....	.....	.....	.....
	".....	99.63	0.32	0.01	.....	.....	.....	.....	.....
	Warwick.....	99.32	0.55	0.02	0.10	.....	.....	.....	0.10
	Waverly.....	99.72	0.11	0.04	.....	.....	.....	.....	.....
Oregon	Chitwood.....	89.99	7.62	.....	.....	.....	.....	.....	.....
	Forest Grove.....	72.45	12.60	10.80	4.10	tr.	.....	.....	.....
Pennsylvania	.....	55.21	17.87	14.75	2.10	.....	4.98	5.09	.....
	Barre.....	98.94	.....	0.58	.....	.....	.....	.....	.....
	Connellsville.....	98.77	0.60	0.22	.....	.....	.....	.....	0.31
	Edge Hill.....	89.00	6.83	2.21	0.07	0.16	1.73	.....	.....
	Galeton.....	92.20	4.60	.....	0.86	.....	.....	0.77	0.92
	Greensburg.....	84.90	8.64	1.31	0.22	0.47	2.64	.....	1.76
	Grenoble.....	64.00	12.88	4.76	7.12	2.56	.....	8.34	.....

TABLE 70. — ANALYSES OF AMERICAN SANDSTONES. — *Continued.*

State.	Location.	Silica.	Alumina.	Iron oxide.	Lime.	Magnesia.	Alkalies.	Carbon dioxide.	Water.
Pennsylvania	Grenoble.....	79.08	12.42	2.50	.....	.....	5.03	.....	0.55
	Hummelstown.....	90.34	4.35	1.83	0.95	0.17	1.49	.....	0.61
	"	88.96	4.74	2.19	0.86	0.44	1.55	.....	0.87
	Hyndman.....	88.13	5.81	2.08	0.20	0.53	2.69	.....	0.49
	Lathrop.....	99.02	0.51	0.29	.....	.....	0.18	.....	.....
	Laurel Run.....	91.40	6.64	0.16	.....	.....	.....	.....	1.28
	Mohnsville.....	94.00	tr.	1.98	1.10	1.00	.....	.....	1.92
	Mt. Gretna.....	84.96	7.78	3.71	0.10	0.38	1.54	.....	1.40
	Newtown.....	91.07	2.68	3.29	0.23	0.33	1.36	.....	0.73
	Point View.....	82.34	11.46	1.07	0.27	0.19	3.93	.....	0.80
	"	97.62	0.80	0.96	0.14	tr.	.....	.....	.....
	Ridgway.....	98.77	0.76	0.14	0.07	0.23	0.13	.....	.....
	Rough Run.....	98.55	1.22	0.21	tr.	tr.	.....	.....	.....
	Smithton.....	97.96	1.15	0.11	.....	.....	0.24	.....	0.54
Utah	Swatara.....	99.02	0.51	0.29	tr.	tr.	.....	.....	0.16
	White Haven.....	91.52	3.80	2.02	0.50	0.22	1.20	.....	0.74
	Yardley.....	90.36	2.17	1.15	2.00	tr.	.....	.....	.....
	.....	82.72	10.29	1.92	0.17	0.36	3.02	.....	1.20
	Jennings Spur.....	83.64	0.46	1.96	4.93	0.70	.....	4.29	3.22
Washington	Kyune.....	71.75	11.50	.....	4.73	.....	.....	.....	7.90
	Heber.....	92.54	3.23	.....	.....	.....	.....	.....	1.35
	Thistle.....	74.23	12.25	.....	4.06	.....	.....	.....	4.81
	Bossburg.....	63.34	13.01	8.51	6.30	0.53	.....	.....	5.14
	Chuckanut Bay.....	90.19	1.92	3.50	0.59	1.78	.....	.....	2.50
	Cumberland.....	96.65	0.06	0.90	0.63	0.22	.....	.....	1.54
	Lilliwaup.....	60.58	18.42	7.90	8.16	1.53	.....	.....	3.64
	Tenino.....	90.84	1.85	3.38	0.65	1.02	.....	.....	2.39

TABLE 70. — ANALYSES OF AMERICAN SANDSTONES. — *Concluded.*

State.	Location.	Silica.	Alumina.	Iron oxide.	Lime.	Magnesia.	Alkalies.	Carbon dioxide.	Water.
Washington	Sucia Island.....	90.21	1.98	3.64	0.72	0.81	.....	.....	2.42
	Wilkeson.....	98.11	0.07	0.89	0.22	0.12	.....	.....	0.76
West Virginia	Boaz.....	89.73	4.67	1.93	0.12	0.43	1.58	.....	1.54
	Cornwallis.....	95.78	2.73	.....	tr.	0.15	.....	.....	1.50
	Underwood.....	82.14	9.04	3.71	0.37	0.32	2.69	.....	2.04
	Clarksburg.....	89.62	6.01	.....	0.92	0.77	.....	.....	2.48
	Fairmont.....	80.88	12.56	0.85	0.72	0.57	1.90	.....	2.99
	Weston.....	93.45	3.73	.....	0.53	0.46	.....	.....	1.88
	Morgantown.....	97.19	2.14	.....	tr.	0.04	.....	.....	0.59
	Sattles.....	88.18	8.47	.....	0.28	0.80	.....	.....	2.48
	Grafton.....	97.83	1.76	.....	tr.	tr.	.....	.....	0.19
	Morgantown.....	93.59	2.98	.....	0.95	0.37	.....	.....	2.22
	Charleston.....	90.41	4.47	1.24	tr.	0.29	1.14	.....	2.45
	Kings Creek.....	95.56	2.65	.....	tr.	0.18	.....	.....	1.45
	Junior.....	97.29	1.29	0.39	0.04	0.07	0.29	.....	0.63
	Bloomington.....	96.50	2.44	.....	0.39	0.07	0.26	.....	0.49
	Alderson.....	90.90	4.61	.....	1.34	0.70	.....	.....	2.50
	Murrayville.....	86.10	5.71	1.71	0.33	0.16	.....	.....	5.65
Wisconsin	Ablemans.....	98.64	1.10	.....	.....	.....	.....	.....	.....
	".....	98.02	0.54	0.69	0.14	0.01	.....	.....	0.29
	".....	97.35	1.83	.....	0.30	0.28	.....	.....	0.24
	Ashland.....	91.40	3.53	2.00	0.25	.....	2.50	.....	0.05
	Houghton.....	86.57	8.43	1.55	.....	.....	3.03	.....	.....
	Bass Island.....	87.02	7.17	3.91	0.11	0.06	1.66	.....	.....
	Port Wing.....	89.33	6.05	1.41	tr.	tr.	2.71	.....	.....
Wyoming	Rawlins.....	95.62	1.12	1.75	0.12	0.17	0.23	0.31	0.52

TEXTURE AND PHYSICAL PROPERTIES.

Shape and Size of Grain. — The sedimentary siliceous rocks are given various names according to their texture. If the component grains are small and of fairly uniform size, the rock is properly a *sandstone*; if the rock contains numerous rounded pebbles, it is a *conglomerate*; while if it is composed of large angular fragments, it is a *breccia*. Regarded as structural materials, however, the sandstones proper demand most consideration, for conglomerates are rarely used for building purposes while breccias are still more rarely employed.

Composition of the Cementing Material. — The cementing material, as noted on a preceding page, may be quartz, clayey matter, iron oxide, or lime carbonate; and a descriptive adjective is frequently employed to describe these differences. When quartz or silica is the cement, the rock is a siliceous sandstone; while when iron oxide or lime carbonate bond the grains together the terms “ferruginous sandstone” and “calcareous sandstone” are respectively used. In some sandstones the cementing material is clayey or argillaceous.

As regards the respective strength and durability of sandstones with different kinds of cementing material, other factors may vary so much that it is not safe to rely on any general rule. Other things being equal, however, the best cementing material is silica, followed by clay, iron oxide, and lime carbonate in the order named. The last is by far the worst.

Value of Microscopic Work on Sandstones. — When a thin section of sandstone is examined under the petrographic microscope, the investigator may hope to secure data covering the following points: (1) mineral character of the component grains; (2) size and shape of grains; (3) mineral character of cementing material; (4) relative proportion of cementing material to grains. In addition to these four points, all of which are usually readily determinable, it is sometimes possible to form some idea as to (5), the probable tenacity and durability of the cementing material. This fifth point is the one of greatest interest to the engineer, and if it were possible to express microscopic results on this point in some quantitative manner the trouble and expense of the investigation would be entirely justified. Even as it is, it will be safest to have the matter investigated in this way. For

it must always be borne in mind, that in dealing with ordinary sandstones we are dealing with the weakest and most uncertain of all building stones, and that nothing should be overlooked which may throw light on the possible future behavior and durability of the particular sandstone which may be under examination.

Physical Properties of Sandstones. — In the following tables are presented the results of tests of strength, density, etc., on a large number of American and British sandstones.

TABLE 71. — PHYSICAL PROPERTIES OF AMERICAN SANDSTONES.

State.	Location.	Tested by	Specific gravity.	Weight per cubic foot.	Absorp- tion.	Compressive strength tests.					
						Size of cube.	No. of tests.	Mini- mum.	Average.	Maxi- mum.	
Arizona	Flagstaff	Navy Yard, D. C. University of Cal.....	2.346	Pounds, 142	Per cent 3.76	Inches, 2	4	lbs. per sq. in. 5,610	lbs. per sq. in. 5,994	lbs. per sq. in. 6,309	
						2	2		6,255	6,760	
California	Colusa..... Angel Island..... " " " " " " San José..... Altamont..... " " " " " " Sespe.....	San Francisco..... State Mining Bureau. " " " " " " " " "	2.558		3.025	1	3	8,440	8,763	8,940	
			2.73	170.6						4,574	
			2.64	165.0						2,400	
			2.68	167.7						1,149	
			2.65	165.6						4,122	
Colorado	Armejo..... Buckhorn..... Glencoe..... Fort Collins..... " " " " " " Gunnison..... " " Cañon City..... Manitou..... " " Trinidad..... Ralston..... Stout..... " " " " " " Coal Creek..... " " " " " " La Porte.....	Col. School Mines.... "	2.379	168.4		2	2		12,019		
						2			18,573		
			2.25	140.7		2			12,752		
			2.432	151.6		2			11,707		
			2.066	128.9		2			12,740		
			2.204	137.5		2			6,127		
			2.301	143.5		2			5,250		
			2.233	139.3		2			5,716		
			2.207	137.7		2			9,250		
			2.339	145.9		2			13,046		
			2.245	140.0		2			10,110		
			2.263	141.2		2			11,118		
			2.033	126.8		2			10,514		
			2.067	128.9		2			2,879		
			2.235	145.0		2			3,570		
						2			10,567		

TABLE 71 — PHYSICAL PROPERTIES OF AMERICAN SANDSTONES. — *Concluded.*

State.	Location.	Tested by	Specific gravity.	Weight per cubic foot.	Absorption.	Compressive strength tests.				
						Size of cube.	No. of tests.	Minimum.	Average.	Maximum.
Kentucky	Langford.....	Watertown Arsenal..	.....	.....	Per cent. 3.00	2	4	.....	15,135	.....
	East Longmeadow...	"	"	.....	.....	6	5	10,223	11,517	12,874
Massachusetts	"	"	.....	.....	.....	5	2	12,210	12,270	12,230
	Red Rock.....	"	.....	.....	.....	6	2	5,296	6,171	6,826
	Calumet.....	Mich. School Mines..	.....	.....	.....	.....	.....	.....	7,470	.....
	Marquette.....	Gillmore.....	2.285	142.8	.....	2	2	5,050	6,162	7,275
	"	"	2.160	135.0	.....	2	2	.....	7,450	.....
	"	"	2.170	135.6	.....	2	2	5,250	5,760	6,270

State.	Location.	Specific gravity.	Weight per cubic foot.	Absorption.	Compression.	Transverse.
Wisconsin	Ashland.....	2.634	Pounds. 133.1	Per cent. 8.92	6,244	.....
	Argyle.....	2.659	134.3	8.85	4,109	.....
	Houghton.....	.....	.....	.....	5,421	.....
	Bass Island.....	2.637	130.5	9.90	5,126	.....
	Ablemans.....	2.574	.....	.....	10,864	.....
	La Valle.....	.....	.....	.....	13,350	.....
	Opposite Fond du Lac	.....	.....	.....	5,300	.....
	Dunnville.....	.....	.....	.....	2,523	.....
	Bayfield.....	.....	.....	.....	4,588	.....
	Port Wing.....	.....	.....	.....	5,105	.....
Houghton.....	.....	.....	.....	4,549	.....

TABLE 72. — PHYSICAL PROPERTIES OF SANDSTONES:
ENGLAND. (BEARE.)

Locality.	Specific gravity.	Pounds per cubic foot.	Absorption, per cent.	Compressive strength, lbs. per sq. inch.
Prudham.....	2.28	142.5	4.66	7,080
Corncockle.....	2.125	132.6	4.57	5,970
Gunnerton.....	2.095	130.8	5.16	5,515
Cragg.....	2.18	136.1	4.13	8,925
Corsehill.....	2.09	130.4	7.94	6,920
Polmaise.....	2.27	141.7	4.58	8,580
White Plean.....	2.215	138.2	4.25	9,535
Arbroath.....	2.42	151.0	2.32	8,680
Auchinlee.....	2.065	128.9	6.90	3,170
Craigleith.....	2.22	138.6	3.61	13,410
White Hailes.....	2.305	143.8	3.71	10,300
Dean Forest.....	2.425	151.4	2.71	8,245
Gatelawbridge.....	2.075	129.5	5.84	7,710
Blue Hailes.....	2.295	143.2	4.70	7,150
Binnie.....	2.165	135.1	5.22	8,850
Hermand.....	2.285	142.6	4.70	7,120
Howley Park.....	2.247	140.3	4.90	7,260
White Grinshill.....	1.963	122.5	7.80	3,260
Darley Top.....	2.227	139.0	3.40	8,040
Hercules Ridge.....	2.21	138.0	3.60	5,225
Bramley Fall.....	2.117	132.2	3.70	3,710
Ackworth.....	2.253	140.7	5.00	6,055
Robin Hood.....	2.313	144.6	3.90	8,930
Lightcliffe.....	2.398	149.6	2.30	15,870
Aspatria.....	1.973	123.2	8.50	3,540

WORKING CLASSIFICATION OF SANDSTONES.

The Necessity for Subdivision. — It has previously been stated that sandstones vary greatly in their composition, structure, and other physical properties, and in preceding statements some attention has been paid to the character and extent of these variations. In view of the facts there developed, it will be readily understood that it is very difficult to frame a subclassification of sandstones which shall be detailed enough to include all the important types and which shall at the same time be serviceable for general use. On the other hand, it is absolutely necessary, from the engineering point of view, that some such grouping be formulated, for without some attempt at subdivision it would be impossible to discuss satisfactorily the physical and industrial properties of a class including such diverse members.

Class A. Quartzites and Quartzitic Sandstones. — Dense, compact stones, composed of sand grains imbedded in a siliceous

ground mass; occasionally the cementing material also contains iron oxide, but never lime or clay, and the silica is always predominant. Owing to their composition and structure, their porosity and absorption are always low, and their compressive strength high. Prominent American examples of this group are the Kettle River sandstone of Minnesota, and the Ablemans quartzite of Wisconsin. Both in this country, in Canada, and in Europe stones of this class occur almost exclusively in the pre-Cambrian and Cambrian geologic periods.

Class B. Graywackes and Dense Flagstones. — The stones of this group are often as dense and compact as those of Class A. Like them the constituent grains are commonly of pure silica (sand), but the cementing material usually contains not only silica but also clay, and occasionally notable percentages of iron oxide; never, however, does it contain more than a trace of lime carbonate. In this class the density is not due so much to the thorough cementation by silica, as to the effects of long-continued pressure acting on a more clayey cementing material. Stones of this group include most of the "graywackes" of Europe, the well-known Hudson River bluestone of New York, and other prominent flagging stones. Since long pressure and at least mild heat were necessary for their consolidation, stones of Class B are commonly found in the Cambrian, Silurian, and Devonian rocks, and rarely higher (at least in the greater portion of the United States).

Class C. Normal Sandstones, Including most "Freestones." — In this class would be included the sandstones of medium density and strength which comprise the bulk of the sandstones used for ordinary building operations. They are markedly lower in density and hardness than the stones of Classes A and B. Owing partly to this fact, they are more readily cut and dressed in all directions than are the more resistant quartzites and flagstones.

Class D. Porous Sandstones. — This class includes a number of porous, loosely compacted sandstones, much inferior for all structural purposes to those included in the preceding classes. Many of them, the Acquia Creek sandstone of Virginia being a well-known example, are of relatively recent geologic age.

Geologic Distribution of Sandstones. — Since sand beds have formed in all ages from the pre-Cambrian to the present day, it is no matter for surprise that commercial sandstones are found

representing almost all of the different geologic periods. In this respect sandstones show a far wider and more general distribution than the granites, and probably wider even than the limestones.

The three most important quarry areas of the United States operate respectively on:

1. The Devonian "bluestones" of New York and Pennsylvania.
2. The Devonian and Carboniferous sandstones of Ohio.
3. The Triassic "brownstones" of the middle Atlantic states, Massachusetts, and Connecticut.

Production of Sandstone in the United States. — The tables following, revised from those annually published by the United States Geological Survey, contain data on the American sandstone industry, covering a series of years.

TABLE 73. — SANDSTONE PRODUCTION OF THE UNITED STATES, 1899-1909.

Year.	Value.	Year.	Value.
1899	\$5,725,395	1905	\$10,006,774
1900	6,471,384	1906	9,169,337
1901	8,138,680	1907	8,871,678
1902	10,594,483	1908	7,594,091
1903	11,262,259	1909	8,010,454
1904	10,273,891	1910	7,930,019

TABLE 74. — SANDSTONE PRODUCTION OF THE UNITED STATES, 1905-1909, BY STATES.

State.	1905.	1906.	1907.	1908.	1909.
Alabama.....	\$28,107	\$40,467	\$48,673	\$34,099	\$77,327
Arizona.....	65,558	33,149	158,435	396,358	298,335
Arkansas.....	58,161	55,703	94,275	42,463	67,956
California.....	685,668	642,166	437,738	330,214	290,034
Colorado.....	453,029	286,544	299,443	181,051	197,105
Connecticut.....	62,618	(^a)	(^a)	55,949	(^b)
Idaho.....	22,265	11,969	24,001	33,394	29,263
Illinois.....	29,115	19,125	14,996	12,218	26,891
Indiana.....	15,421	30,740	15,425	3,342	4,119
Iowa.....	9,335	5,600	3,542	2,337	2,443
Kansas.....	79,617	42,809	46,831	67,950	19,560
Kentucky.....	280,579	125,123	98,450	78,732	90,835
Maryland.....	12,984	9,533	13,859	6,262	10,584
Massachusetts.....	367,461	260,721	243,323	241,462	^c 457,962
Michigan.....	123,123	65,395	53,003	39,103	36,084
Minnesota.....	294,640	285,433	300,204	197,184	299,358
Missouri.....	27,686	20,951	35,289	17,954	28,763
Montana.....	45,116	37,462	39,216	51,564	73,443
Nebraska.....	120	6,899	11,609	^d 15,815	.....
Nevada.....	1,500	.....	.....	(^e)	(^f)
New Jersey.....	294,719	215,142	177,667	154,422	189,098
New Mexico.....	101,522	42,574	12,450	^g 10,410	4,963
New York.....	^h 1,831,756	^{hc} 1,905,892	^{hc} 1,978,117	^h 1,774,843	^h 1,430,830
North Carolina.....	4,483	3,531	4,105	ⁱ 12,266	.....
North Dakota.....	1,055	44	3,260	(^j)	(^k)
Ohio.....	1,744,472	1,426,645	1,591,148	1,244,752	1,639,006
Oklahoma.....	15,112	40,861	43,403	57,124	59,855
Oregon.....	1,229	25,950	3,904	(^j)	^g 4,811
Pennsylvania.....	^h 2,487,939	^h 2,724,874	^h 2,064,913	^h 1,368,784	^h 1,637,794
South Dakota.....	193,408	145,966	143,585	128,554	^l 118,029
Tennessee.....	8,715	14,136	16,523	(^m)	(ⁿ)
Texas.....	123,281	111,533	108,047	154,948	61,600
Utah.....	43,429	137,529	24,298	25,097	71,235
Virginia.....	2,000	5,100	(ⁿ)	(^m)	28,574
Washington.....	124,910	169,500	295,585	464,587	335,470
West Virginia.....	171,309	113,369	^o 197,926	127,149	^p 201,038
Wisconsin.....	161,741	181,986	236,183	219,130	204,959
Wyoming.....	33,591	24,715	32,252	44,574	13,130
Total.....	10,006,774	9,169,337	8,871,678	7,594,091	8,010,454

^a Included in New York.^b Included in Massachusetts.^c Includes Connecticut.^d Includes North Dakota and Oregon.^e Included with New Mexico.^f Included in Oregon.^g Includes Nevada.^h Includes bluestone.ⁱ Includes Tennessee and Virginia.^j Included with Nebraska.^k Included in South Dakota.^l Includes North Dakota.^m Included with North Carolina.ⁿ Included in West Virginia.^o Includes a small value for Virginia.^p Includes Tennessee.

TABLE 75. — SANDSTONE PRODUCTION, 1903-1909, BY USES.

Year.	Building stone.	Rubble and riprap.	Paving, curbing, and flags.	Crushed stone.	Ganister.
1903	\$6,403,969	\$917,080	\$2,863,737	\$827,585	\$187,689
1904	5,125,858	799,251	3,045,917	1,041,493	136,957
1905	4,702,189	818,870	3,008,013	1,008,270	186,123
1906	4,275,669	756,762	2,866,802	889,894	284,066
1907	3,154,783	845,859	3,451,238	987,528	308,520
1908	2,605,381	1,039,929	2,747,489	906,317	175,325
1909	3,349,519	642,533	2,493,250	1,212,931	240,409

TABLE 76. — VALUE AND USES OF BLUESTONE PRODUCED IN NEW YORK AND PENNSYLVANIA IN 1908 AND 1909.

1908.

State.	Building purposes.	Flagging.	Curbing.	Crushed stone.	Other purposes.	Total value.
New York.....	\$415,652	\$413,920	\$313,319	\$9,219	\$68,852	\$1,220,962
Pennsylvania...	186,093	217,690	116,197	6,985	14,933	541,898
Total.....	601,745	631,610	429,516	16,204	83,785	1,762,860

1909.

New York.....	\$378,960	^a \$264,770	^b \$241,253	\$21,224	\$11,389	\$917,596
Pennsylvania...	159,193	^c 195,525	^d 83,538	70,269	20,281	528,806
Total.....	538,153	460,295	324,791	91,493	31,670	1,446,402

^a This value represents 4,129,324 square feet of stone.^b This value represents 1,968,329 linear feet of stone.^c This value represents 2,665,480 square feet of stone.^d This value represents 437,281 linear feet of stone.

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TABLE 77. — SANDSTONE PRODUCTION IN 1909, BY STATES AND USES.

State or Territory.	Rough building.	Dressed building.	Ganister.	Paving.	Curbing.	Flagging.	Rubble.	Riprap.	Crushed stone.			Other.	Total.
									Road making.	Railroad ballast.	Concrete.		
Alabama.....	\$3,951	\$23					\$15,347	\$325			\$51,432	\$6,249	\$77,327
Arizona.....	46,126	70,200		\$350		\$398	126,500	1,503			51,203		298,335
Arkansas.....	5,638					650	1,000	6,910		\$2,055	20,611		67,956
California.....	32,549	63,579		2,240	\$18,022		560	27,171	\$1,940	13,185	35,360	6,875	290,034
Colorado.....	56,678	42,222	\$17,384	8,351	11,922	30,202	15,982	50	61,150	51,769	13,784	530	197,406
Connecticut.....													(g)
Idaho.....	20,111	6,038					3,114						28,283
Illinois.....	2,047	2,420	4				624	22	21,774				26,391
Indiana.....	2,790				250		255	774				50	4,119
Iowa.....	1,357	831					55	100	100				2,443
Kansas.....	11,748						1,019					206	19,560
Kentucky.....	33,863	55,579			144	6,443		28	45				90,335
Maryland.....	3,508		6,786	290	40	1,320	26,000	11,147	48,517		89,021	147	10,384
Massachusetts.....	222,620	60,470					6,294						b 457,962
Michigan.....	12,985	16,805					38,656	1,042			10,235	660	36,084
Minnesota.....	11,982	70,464		118,653	3,649		5,357	5,001	44,017			357	299,358
Missouri.....	6,245	11,350		262	191		494	10,653				850	28,763
Montana.....	9,237	52,209											73,443
Nevada.....													(c)
New Jersey.....	110,987	39,090				1,208	178		32,435		5,100	100	189,098
New Mexico.....	4,963												4,963
New York.....	147,401	301,240		235,961	347,824	291,439	26,104	9,624	25,181	4,476	26,509	15,071	d 1,430,830
North Dakota.....													(e)
Ohio.....	372,680	403,641	600	500	366,038	391,340	5,320	11,623	31,168	9,100	25,410	21,586	1,639,006
Oklahoma.....	8,612						6,063				44,536	644	59,855
Oregon.....	508	155					150				4,000		f 4,811
Pennsylvania.....	336,113	234,274	169,218	56,088	178,117	231,858	45,374	66,261	69,872	146,818	90,469	13,332	d 1,637,794
South Dakota.....	26,118	12,121		45,870	900	40	9,165	8,121			15,094	600	g 118,029
Tennessee.....													(h)
Texas.....	9,000	24,500		250			1,550	4,700	10,800		10,800		61,600
Utah.....	61,726	767		4,737		130		200			25	3,650	71,235
Virginia.....	500	300							500	26,474	700	100	28,574
Washington.....	43,139	81,830					1,075	82,778					335,470
West Virginia.....	38,925	61,448		126,048	1,889		22,295	2,500			31,081	805	i 201,038
Wisconsin.....	45,994	36,059					6,202	26,107			10,613		204,959
Wyoming.....	11,242	563	46,417				1,325		33,477				13,130
Total.....	1,701,341	1,648,178	240,409	600,200	937,767	955,283	365,893	276,640	363,831	283,117	535,983	71,812	8,010,454

a Includes Massachusetts.

b Includes Connecticut.

c Includes in Oregon.

d Includes bluestone.

e Includes in South Dakota.

f Includes Nevada.

g Includes North Dakota.

h Includes in West Virginia.

i Includes Tennessee.

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CHAPTER IX.

LIMESTONES.

THOUGH marbles are, from a strictly geological point of view, merely special varieties of limestone, they occupy so distinct a position in the stone trade as to require separate consideration. For this reason the two classes of stone will be treated in separate chapters in the present volume; Chapter IX being devoted to the consideration of the ordinary structural limestones, while Chapter X will contain data on the marbles and decorative limestones. The origin of limestones in general will of course be discussed in the present chapter.

ORIGIN AND CHEMICAL COMPOSITION.

Origin of Limestones.* — Limestones have been formed largely by the accumulation at the sea bottom of the calcareous remains of such organisms as the foraminifera, corals, and molluscs. Many of the thick and extensive limestone deposits of the United States were probably deep-sea deposits formed in this way. Some of these limestones still show the fossils of which they were formed, but in others all trace of organic origin has been destroyed by the fine grinding to which the shells and corals were subjected before their deposition at the sea bottom. It is probable also that part of the calcium carbonate of these limestones was a purely chemical deposit from solution, cementing the shell fragments together.

A far less extensive class of limestones, though very important in the present connection, owe their origin to the indirect action of organisms. The "marls," which have until recently been so important as Portland-cement materials, fall in this class. As the class is of limited extent, and includes no products used in structural work, its method of origin may be dismissed here.

Deposition from solution by purely chemical means has un-

* For a more detailed discussion of this subject the reader will do well to consult Chapter VIII of Prof. J. F. Kemp's "Handbook of Rocks."

doubtedly given rise to numerous important limestone deposits. When this deposition took place in caverns or in the open air it gave rise to onyx deposits and to the "travertine marls" of certain Ohio and other localities; when it took place in isolated portions of the sea, through the evaporation of the sea water, it gave rise to the limestone beds which so frequently accompany deposits of salt and gypsum.

Shells as Sources of Limestone.* — Most molluscan shells consist essentially of lime carbonate, with commonly very small percentages (less than 1 per cent) of magnesium carbonate, and traces of alkalis, phosphoric acid, etc. The analyses given in Table 78 will serve to illustrate the composition of the shells of three common species of molluscs.

TABLE 78. — ANALYSES OF VARIOUS MOLLUSCAN SHELLS.

	1	2	3	4	5	6
Silica (SiO_2).....	3.30	1.49	n.d.	0.20	0.16	n.d.
Alumina (Al_2O_3).....	0.08	.....	.....	.....	.....	.....
Iron oxide (Fe_2O_3).....	0.17	0.04	n.d.	0.04	.....	.....
Lime (CaO).....	52.14	53.37	n.d.	52.86	54.55	54.38
Magnesia (MgO).....	0.25	.....	.....	.....	.....	.....
Alkalis (K_2O , Na_2O).....	0.35	.....	.....	.....	.....	.....
Sulphur trioxide (SO_3).....	0.16	0.81	0.80	0.35	0.28	0.28
Phosphorus pentoxide (P_2O_5).....	n.d.	0.11	n.d.	0.05	0.001	n.d.
Carbon dioxide (CO_2).....	41.61	40.60	n.d.	41.02	42.82	n.d.
Water.....	.....	.....	.....	.....	.....	.....
Organic matter.....	2.32	3.48	3.17	5.02	2.01	2.04

1. Oyster shell; L. P. Brown and J. S. H. Koiner, analysts; American Chemical Journal, Vol. 11, pp. 36-37.
- 2, 3. Oyster shell; How, analyst; American Journal of Science, 2d series, Vol. 41, p. 380.
4. Mussel shell; How, analyst; American Journal of Science, 2d series, Vol. 41, p. 380.
- 5, 6. Periwinkle shell; How, analyst; American Journal of Science, 2d series, Vol. 41, pp. 379-381.

These analyses show that in ordinary practice an oyster shell may be expected to contain, as its principal impurities, several

* Brown, L. P., and Koiner, J. S. H. Analysis of oyster shells and oyster-shell lime. American Chemical Journal, Vol. 11, pp. 36, 37. 1889.

How, Dr. On the comparative composition of some recent shells, a Silurian fossil shell, and a Carboniferous shell limestone. American Journal of Science 2d series, Vol. 41, pp. 379-384. 1866.

per cent of organic matter and from a trace to 5 per cent of silica, iron oxide, and alumina. The amount of these last clayey impurities present will doubtless vary with the cleanness of the shell, as it is probable that they are in large part purely *external* impurities.

Chemical Composition of Limestone. — Calcite, a rock-forming mineral in all limestones, is carbonate of lime. A theoretically pure limestone is merely a massive form of the mineral calcite. Such an ideal limestone would therefore consist entirely of calcium carbonate or carbonate of lime, with the formula $\text{CaCO}_3(\text{CaO} + \text{CO}_2)$, corresponding to the composition calcium oxide (CaO) 56 per cent, carbon dioxide or carbonic acid (CO_2) 44 per cent.

As might be expected, the limestones we have to deal with in practice depart more or less widely from this theoretical composition. These departures from ideal purity may take place along either of two lines:

- a. The presence of magnesia in place of part of the lime;
- b. The presence of silica, iron, alumina, alkalies, or other impurities.

It seems advisable to discriminate between these two cases, even though a given sample of limestone may fall under both heads, and they will therefore be discussed separately.

The Presence of Magnesia in Place of Part of the Lime. — The theoretically pure limestones are, as above noted, composed entirely of calcium carbonate and correspond to the chemical formula CaCO_3 . Setting aside for the moment the question of the presence or absence of such impurities as iron, alumina, silica, etc., it may be said that lime is rarely the only base in a limestone. During or after the formation of the limestone a certain percentage of magnesia is usually introduced in place of part of the lime, thus giving a more or less magnesian limestone. In such magnesian limestones part of the calcium carbonate is replaced by magnesium carbonate (MgCO_3), the general formula for a magnesian limestone being, therefore,



In this formula x may vary from 100 per cent to zero, while y will vary inversely from zero to 100 per cent. In the particular case of this replacement where the two carbonates are united in equal *molecular* proportions, the resultant rock is called dolo-

mite. It has the formula $\text{CaCO}_3\text{MgCO}_3$, corresponding to the composition calcium carbonate 54.35 per cent, magnesium carbonate 45.65 per cent. In the case where the calcium carbonate has been entirely replaced by magnesium carbonate, the resulting pure carbonate of magnesia is called magnesite, having the formula MgCO_3 and the composition magnesia (MgO) 47.6 per cent, carbon dioxide (CO_2) 52.4 per cent.

Rocks of this series may therefore vary in composition from pure calcite limestone at one end of the series to pure magnesite at the other. The term limestone has, however, been restricted in general use to that part of the series lying in composition between calcite and dolomite, while all those more uncommon phases carrying more magnesium carbonate than the 45.65 per cent of dolomite are usually described simply as more or less impure magnesites.

Though magnesia is often described as an "impurity" in limestone, this word, as can be seen from the preceding statements, hardly expresses the facts in the case. The magnesium carbonate present, whatever its amount, simply serves to replace an equivalent amount of calcium carbonate, and the resulting rock, whether little or much magnesia is present, is still a pure carbonate rock. With the impurities to be discussed in later paragraphs, however, this is not the case. Silica, alumina, iron, sulphur, alkalies, etc., when present are actual impurities, not merely chemical replacements of part of the calcium carbonate.

The Presence of Silica, Alumina, Iron, and Other Impurities.—If a number of limestone analyses be examined, it will be found that the principal impurities present are silica, alumina, iron oxide, sulphur, and alkalies.

Silica when present in a marble or crystalline limestone is usually combined with alumina, iron, lime, or magnesia, and occurs therefore in the form of a silicate mineral. In an ordinary limestone it is very often present as masses or nodules of chert or flint, or else combined with alumina as clayey matter. In the softer limestones, such as the chalks and marls, the silica may be present as grains of sand.

Alumina is commonly present combined with silica either as grains of a silicate mineral or as clayey matter.

Iron may be present as carbonate, as oxide, or in the sulphide form as the mineral pyrite.

Sulphur is commonly present in small percentages in one of two forms: as pyrite or iron disulphide (FeS_2) or as gypsum or lime sulphate ($\text{CaSO}_4 + 2 \text{H}_2\text{O}$).

The alkalis soda and potash are frequently present in small quantity, probably in the form of carbonates.

Average Composition of Limestones. — On succeeding pages a series of tables containing a large number of analyses of American limestones of commercial importance will be presented. Before doing this, however, it is of interest to endeavor to get some idea of the normal or average chemical composition of the stones of this group. Fortunately a very interesting pair of average analyses are available for this purpose, and these are reprinted here as Table 79.

TABLE 79. — AVERAGE ANALYSES OF AMERICAN LIMESTONES. (F. W. CLARKE.)

	A.	B.
Silica (SiO_2).....	5.19	14.09
Alumina (Al_2O_3) *.....	0.87	1.83
Iron oxide (Fe_2O_3).....	0.54	0.77
Lime (CaO).....	42.61	40.60
Magnesia (MgO).....	7.90	4.49
Soda (Na_2O).....	0.05	0.62
Potash (K_2O).....	0.33	0.58
Phosphorus pentoxide (P_2O_5).....	0.04	0.42
Sulphur (S).....	0.09	0.07
Sulphur trioxide (SO_3).....	0.05	0.07
Carbon dioxide (CO_2).....	41.58	35.58
Combined water †.....	0.56	0.88
Moisture.....	0.21	0.30

* Including very small amounts of titanic oxide (TiO_2).

† Including organic matter.

- A. Composite analyses of 345 samples of American limestones, uses not specified. H. N. Stokes, analyst.
- B. Composite analyses of 498 samples of American limestones used for building purposes. H. N. Stokes, analyst.

TABLE 80.* — ANALYSES OF LIMESTONES: INDIANA.
(BEDFORD STONE.)

Locality.	Silica.	Alumina and Iron.	Lime car- bonate.	Magnesium carbonate.	Alkalies.	Water.
Bedford.....	0.64	0.15	98.27	0.84	.....	.....
Bedford.....	0.50	0.98	96.60	0.27	0.40	0.61
Bedford.....	0.63	0.39	98.20	0.39	.....	.....
Bedford.....	1.69	0.49	96.79	0.23	0.32	0.41
Big Creek.....	0.15	0.64	93.80	4.01	.....	1.09
Big Creek.....	0.50	0.71	93.07	4.22	.....	1.19
Bloomington.....	1.74	0.29	95.62	0.89	.....	0.59
Bloomington.....	1.60	0.18	95.55	0.93	.....	0.42
Bloomington.....	0.65	1.00	95.54	0.40	0.55	0.25
Harrison County.....	0.31	0.32	98.09	n.d.	0.40	0.12
Hunter Valley.....	0.86	0.16	98.11	0.92	.....	.....
Romona.....	1.26	0.18	97.90	0.65	.....	.....
Salem.....	1.13	1.06	96.04	0.72	0.15	0.10
Spencer.....	0.70	0.91	96.79	0.23	0.32	0.41
Stinesville.....	0.90	3.00	95.00	0.22	0.83	0.05
Twin Creek.....	0.76	0.15	98.16	0.97	.....	.....

* 21st Ann. Rep. Ind. Dept. Geol., p. 320.

TABLE 81.* — ANALYSES OF LIMESTONES: MISSOURI.

Locality.	Silica.	Alu- mina and iron oxides.	Lime carbon- ate.	Lime.	Magne- sium carbon- ate.	Magne- sia.	Carbon dioxide.	Water.
Bowling Green.....	13.99	1.62	49.77	.....	34.46	.....	.....	.....
Breckenridge.....	2.93	0.54	.....	54.22	.....	0.22	42.58	.....
Cape Girardeau.....	0.10	0.14	.....	55.73	.....	0.24	43.91	0.27
Cape Girardeau.....	2.93	0.45	87.23	.....	9.26	.....	.....	.....
Carthage.....	0.69	0.21	98.57	.....	0.65	.....	.....	.....
De Soto.....	11.19	0.68	48.18	.....	39.99	.....	.....	.....
Hannibal.....	0.26	0.14	98.87	.....	0.62	.....	.....	.....
Jackson.....	4.66	0.28	.....	52.29	.....	0.97	41.72	.....
Osceola.....	0.99	0.17	98.59	.....	0.09	.....	.....	.....
Phenix.....	0.21	0.23	99.06	.....	0.58	.....	.....	.....
Princeton.....	1.88	0.78	96.22	.....	1.01	.....	.....	.....
Republic.....	0.45	0.12	.....	55.48	.....	0.03	43.70	0.42
Sedalia.....	17.69	1.08	49.21	.....	31.57	.....	.....	.....
Springfield.....	0.36	0.13	99.34	.....	0.22	.....	.....	.....
Springfield.....	4.51	0.52	92.24	.....	2.35	.....	.....	.....
St. Louis.....	0.54	0.25	.....	55.42	.....	0.25	43.42	.....
St. Louis.....	2.36	0.27	96.09	.....	0.90	.....	.....	.....

* Rept. Mo. Bur. Geol., Vol. 2, 2d series, p. 308.

TABLE 82. — ANALYSES OF LIMESTONE: WISCONSIN.

	1	2	3	4	5	6
Silica.....	3.17	6.32	0.02	2.12	1.09	0.61
Alumina }	1.95	1.02	0.01	0.59	0.33	{ 1.97 2.18*
Ferric oxide }						
Ferrous oxide.....						
Lime carbonate.....	49.97	50.96	54.74	53.51	54.42	52.48
Magnesium carbonate.....	44.58	41.75	45.07	43.54	44.17	41.94

* Fe_2CO_3 .

1. Duck Creek; W. W. Daniells, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
2. Genesee; W. W. Daniells, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
3. Knowles; W. W. Daniells, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
4. Marblehead; W. W. Daniells, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
5. Sturgeon Bay; W. W. Daniells, analyst; Bull. 4, Wis. Geol. Sur., p. 420.
6. Washburn, Bayfield County; C. W. Hall, analyst; Min. Res. U. S., 1903, p. 205.

PHYSICAL CHARACTERS AND TESTS.

Texture and Structure. — In texture limestones differ among themselves even more widely than do sandstones, for in addition to differences in size and shape of grain, there are also important structural differences to be considered. Many of these points of difference between individual limestones are obvious enough when a hand specimen is examined, but occasionally differences are only brought to notice by the microscope. This last case is relatively rare, however, and the examination of thin sections of limestone under the petrographic microscope does not often yield enough information to justify the trouble and expense.

Color. — Limestones when absolutely pure are white, but as actually found in nature they show a wide range of colors from pure white through yellowish, bluish, and gray tints to deep black. Pink, reddish, and green limestones also occur, but in these cases the limestone is usually polished and marketed as a marble. The commonest tints are, however, light gray and grayish-blue. These variations in color are due to the character and amount of impurities present, the principal coloring agents being organic matter and iron oxide.

The color, whatever its tint, may be uniformly distributed throughout the stone, or it may show blotching or banding with

two or more tints. Such irregular distribution of color is undesirable in an ordinary limestone; but if the colors show pleasing contrasts, and the texture of the stone admits of a good polish, the material may be valuable as a decorative marble.

Varieties of Limestone. — A number of terms are in general use for the different varieties of limestone, based upon differences of origin, texture, composition, etc. The more important of these terms will be briefly defined.

The *marbles* are limestones which, through the action of heat and pressure, have become more or less distinctly crystalline. The term *marl* as at present used in cement manufacture is applied to a loosely cemented mass of lime carbonate formed in lake basins. *Calcareous tufa* and *travertine* are more or less compact limestones deposited by spring or stream waters along their courses. *Oolitic* limestones, so called because of their resemblance to a mass of fish-roe, are made up of small rounded grains of lime carbonate. *Chalk* is a fine-grained limestone composed of finely comminuted shells, particularly those of the foraminifera. The presence of much silica gives rise to a *siliceous* or *cherty* limestone. If the silica present is in combination with alumina, the resulting limestone will be *clayey* or *argillaceous*.

Physical Characters of Limestones. — In texture, hardness, and compactness the limestones vary from the loosely consolidated marls through the chalks to the hard, compact limestones and marbles. Parallel with these variations are variations in absorptive properties and density. The chalky limestones may run as low in specific gravity as 1.85, corresponding to a weight of, say, 110 pounds per cubic foot, while the compact limestones commonly used for building purposes range in specific gravity between 2.3 and 2.9, corresponding approximately to a range in weight of from 140 to 185 pounds per cubic foot.

TABLE 83. — COMPRESSIVE STRENGTH OF AMERICAN LIMESTONES.

State.	Locality.	Tested by	No. of tests.	Size of cube.	Compressive strength, pounds per square inch.		
					Min.	Aver.	Max.
				In.			
Arkansas	Eureka Springs, Carroll Co.	Watertown Arsenal	.....	.....	.....	21,397	.....
	Beaver, Carroll Co.	Navy Department	.....	.....	.....	20,581	.....
	Johnson, Carroll Co.	Ark. Indust. Inst.	.....	.....	.....	15,550	.....
Illinois	Kankakee, Kankakee Co.	Univ. Illinois	.....	.....	.....	13,544	.....
	Niota, Hancock Co.	Watertown Arsenal	.....	.....	.....	14,120	.....
Indiana	Ellettsville	Rose Polytech. Inst.	.....	.....	.....	5,900	6,900
	Salem	" " "	3	4	.....	5,900	11,700
	Bloomington	" " "	3	4	.....	8,400	11,400
	Hunter Valley	" " "	3	4	.....	3,400	4,600
	Romona	" " "	3	4	.....	6,400	7,800
	Bedford	" " "	3	4	.....	3,400	6,800
	"	" " "	3	4	.....	3,300	4,800
	"	" " "	3	4	.....	6,400	9,700
	Bloomington	" " "	3	4	.....	4,400	6,900
	"	" " "	3	4	.....	4,700	8,200
	"	" " "	3	4	.....	4,500	7,500
	"	" " "	3	4	.....	5,800	6,200
	Stinesville	" " "	3	4	.....	4,100	5,635
Kentucky	Bowling Green, Warren Co.	Watertown Arsenal	3	4	.....	6,532	7,009
	Caden, Warren Co.	" " "	6	5	.....	5,656	7,425
Missouri	Carthage	" " "	4	4	.....	13,660	14,947
	"	Missouri Geol. Sur.	11	4	.....	15,282	17,130
	Bowling Green	" " "	3	4	.....	8,792	20,261
	Breckenridge	" " "	2	4	.....	6,944	10,721
	Columbia	" " "	2	4	.....	9,829	8,267
	De Soto	" " "	4	4	.....	15,980	10,290
	Hannibal	" " "	10	4	.....	9,214	18,575
	Jackson	" " "	2	4	.....	27,813	10,679
	Joplin	" " "	5	4	.....	11,870	29,306
	Jefferson City	" " "	7	4	.....	16,319	14,102
	"	" " "	7	4	.....	11,545	19,751
	"	" " "	4	4	.....	11,260	12,582
	Kahoka	" " "	4	4	.....	11,198	12,544
	Kansas City	" " "	4	4	.....	12,641	13,124
	Koeltztown	" " "	4	4	.....	24,662	12,985
	Noel	" " "	4	4	.....	12,062	25,360
	Phenix	" " "	6	4	.....	11,270	14,176
	Pierce City	" " "	4	4	.....	8,705	13,013
	Princeton	" " "	4	4	.....	8,486	12,704
	Rolla	" " "	3	4	.....	12,995	10,071
New York	Sedalia	" " "	4	4	.....	10,453	14,053
	Sheffield	" " "	2	4	.....	20,779	13,140
	Springfield	" " "	7	4	.....	15,063	22,438
	St. Louis	" " "	.....	.....	.....	.....	17,149
	Buffalo	Watertown Arsenal	2	4	.....	18,496	23,724
	"	" " "	.....	.....	.....	.....	28,951
Texas	Austin	Rock Island Arsenal	.....	.....	.....	3,422	.....
	"	" " "	.....	.....	.....	8,207	.....
	"	" " "	.....	.....	.....	2,279	.....
	Duval	" " "	.....	.....	.....	6,303	.....
	Honey Creek, Burnet Co.	" " "	.....	.....	.....	14,950	.....
	Slaughter Creek	" " "	4	.....	.....	18,660	20,320
	Bear Creek	" " "	4	.....	.....	7,305	12,255
	Cedar Park	Univ. of Texas	1	1	.....	2,300	.....
	Round Rock	" " "	1	1	.....	1,495	.....
	McLennan Co.	" " "	1	1	.....	3,180	.....
	Lueders, Jones Co.	" " "	1	1	.....	2,487	.....
Wisconsin	Bridgeport	Wisconsin Geol. Sur.	.....	.....	.....	6,675	8,394
	Burlington	" " "	.....	.....	.....	12,066	.....
	Duck Creek	" " "	.....	2	.....	23,783	24,783
	Fountain City	" " "	.....	.....	.....	5,830	.....
	Genesee	" " "	.....	2	.....	36,731	.....
	Knowles	" " "	.....	2	.....	29,189	.....
	Lannon	" " "	.....	.....	.....	31,936	.....
	Marblehead	" " "	.....	.....	.....	42,787	.....
	Sturgeon Bay	" " "	6	.....	.....	29,526	30,941
	Waukesha	Univ. of Wisconsin	.....	.....	.....	19,234	.....
	Wauwatosa	Wisconsin Geol. Sur.	.....	.....	.....	17,647	18,379
	"	" " "	.....	.....	.....	.....	19,111

TABLE 84. — PHYSICAL TESTS OF LIMESTONES: ENGLAND.
(BEARI.)

Locality.	Specific gravity.	Weight per cubic foot.	Absorption, per cent.	Compressive strength, pounds per square inch.
White Man's Field.....	2.245	140.1	5.01	7,185
Red Man's Field.....	2.295	143.2	4.58	9,210
Yellow Man's Field.....	2.33	145.4	4.62	8,980
Anston.....	2.117	132.2	7.50	4,700
Ancaster.....	2.25	140.4	6.27	2,860
	2.505	156.3	2.42	8,595
	2.205	137.6	6.84	4,465
Portland.....	1.995	124.5	11.10	2,285
	2.120	132.3	7.51	3,190
	2.05	127.9	8.10	1,585
Ketton.....	2.80	174.7	.....	14,875
D.....	2.067	129.0	11.12	1,705
Corsham Down.....	1.93	120.5	12.88	1,010
Farleigh Down.....	2.19	136.7	8.03	2,255
Monks Park.....	2.05	127.9	7.79	1,515
Box Ground.....	2.06	128.6	5.99	2,005
Coombe Down.....	2.14	133.6	8.88	2,185
Corngrit.....	2.023	126.3	10.85	1,540
Stoke Ground.....	2.13	132.9	7.74	1,660
Winsley Ground.....	2.12	132.3	8.03	1,735
Westwood Ground.....	2.087	130.3	8.85	1,910
	2.41	150.4	3.36	2,815
	2.003	125.0	10.87	1,735
Doulting.....	2.18	136.0	?	2,585
Ham Hill.....				

DISTRIBUTION AND PRODUCTION.

Geologic and Geographic Distribution of Limestones. — Limestones occur in every state and territory in the United States, though of course some states (Delaware, North Dakota, Louisiana, etc.) are so poorly supplied that they can never become important lime producers, while other states are almost entirely underlain by limestone strata. Geologically, the limestone utilized in various parts of the United States ranges entirely through the geological column, from the pre-Cambrian to the Pleistocene, inclusive.

Under such conditions of wide geographic and geologic distribution it is not practicable to give a summary of any value in the present volume. The list of references given in the following pages will enable the reader to ascertain the facts regarding the limestones of any given state in which he may be interested.

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Production of Limestone in the United States.—The following tables, quoted from those annually published by the United States Geological Survey, contain statistics on the American limestone industries for a series of years.

TABLE 85. — LIMESTONE PRODUCTION OF THE UNITED STATES, 1899-1909.

Year.	Value.	Year.	Value.
1899	\$13,889,302	1905	\$26,025,210
1900	13,556,523	1906	27,327,142
1901	18,202,843	1907	31,737,631
1902	20,895,385	1908	27,682,002
1903	22,372,109	1909	32,070,401
1904	22,178,964	1910	34,603,678

TABLE 86. — LIMESTONE PRODUCTION, BY STATES, 1905-1909.

State or Territory.	1905.	1906.	1907.	1908.	1909.
Alabama.....	\$532,103	\$579,344	\$694,699	\$479,730	\$700,642
Arizona.....	135	40	64,975	<i>a</i> 50,130	(<i>b</i>)
Arkansas.....	154,818	48,844	52,207	61,971	112,468
California.....	49,902	80,205	177,333	237,320	283,869
Colorado.....	289,920	373,158	502,751	378,822	355,136
Connecticut.....	1,558	1,171	1,476	<i>c</i> 3,727	<i>c</i> 5,023
Florida.....	5,800	1,450	15,000	41,910	<i>d</i> 49,856
Georgia.....	9,030	16,042	22,278	8,495	34,593
Hawaii.....					(<i>e</i>)
Idaho.....	14,105	12,600	15,900	36,000	(<i>e</i>)
Illinois.....	3,511,890	2,942,331	3,774,346	3,122,552	4,234,927
Indiana.....	3,189,259	3,725,565	3,624,126	3,643,261	3,749,239
Iowa.....	451,791	493,815	560,582	530,945	525,277
Kansas.....	923,389	849,203	813,748	403,176	892,335
Kentucky.....	744,465	795,408	891,500	810,190	903,874
Louisiana.....					(<i>f</i>)
Maine.....	7,428	2,000	1,350	(<i>g</i>)	(<i>g</i>)
Maryland.....	149,402	170,046	142,825	128,591	197,939
Massachusetts.....	65,908	10,750	1,837	1,950	
Michigan.....	544,754	656,269	760,333	669,017	750,589
Minnesota.....	555,401	632,115	735,319	667,095	698,309
Missouri.....	2,238,164	1,988,334	2,153,917	2,130,136	2,111,283
Montana.....	103,123	141,082	124,690	134,595	154,064
Nebraska.....	225,119	276,381	312,630	330,570	293,830
New Jersey.....	147,353	221,141	274,452	172,000	224,017
New Mexico.....	7,200	125,493	193,732	(<i>h</i>)	<i>i</i> 140,801
New York.....	1,970,968	2,204,724	2,898,520	2,584,559	2,622,353
North Carolina.....	16,500	30,583	22,328	(<i>j</i>)	(<i>j</i>)
Ohio.....	2,850,793	3,025,038	3,566,822	3,519,557	4,020,046
Oklahoma.....	168,924	171,983	189,568	257,066	450,055
Oregon.....	8,600	7,480	5,750	6,230	
Pennsylvania.....	4,499,503	4,865,130	5,821,275	4,057,471	5,073,825
Rhode Island.....	300	678	750	(<i>g</i>)	(<i>g</i>)
South Dakota.....	6,653	10,400	11,600	(<i>k</i>)	<i>l</i> 49,328
Tennessee.....	401,622	481,952	385,450	<i>m</i> 535,882	<i>m</i> 589,949
Texas.....	171,847	239,125	267,757	314,571	341,528
Utah.....	232,519	248,868	306,344	253,088	169,700
Vermont.....	11,095	14,728	23,126	20,731	18,839
Virginia.....	212,660	260,343	362,062	280,542	342,656
Washington.....	52,470	49,192	62,317	31,660	38,269
West Virginia.....	671,318	628,602	855,941	645,385	864,392
Wisconsin.....	804,081	891,746	1,027,095	1,102,009	1,047,044
Wyoming.....	23,340	53,783	18,920	<i>n</i> 31,168	24,346
Total.....	26,025,210	27,327,142	31,737,631	27,682,002	32,070,401

a Includes New Mexico.*b* Included in New Mexico.*c* Includes Maine and Rhode Island.*d* Includes Louisiana.*e* Included in South Dakota.*f* Included in Florida.*g* Included with Connecticut.*h* Included with Arizona.*i* Includes Arizona.*j* Included with Tennessee.*k* Included with Wyoming.*l* Includes Hawaii and Idaho.*m* Includes North Carolina.*n* Includes South Dakota.

TABLE 87.—LIMESTONE PRODUCTION, BY STATES AND USES, 1909.

State or Territory.	Rough building.	Dressed building.	Paving.	Curbing.	Flagging.	Rubble.	Riprap.
Alabama.....	\$775	\$27,197	\$2,000	\$46,115		\$8,460	\$19,200
Arkansas.....	23,655	74,413				650	
California.....	12,341						
Connecticut.....							90
Florida.....	6,955					684	14,400
Georgia.....	954						
Illinois.....	62,395	34,323	2,600	4,348	\$4,651	368,605	115,413
Indiana.....	1,235,524	1,353,180	534	109,454	4,921	14,100	7,939
Iowa.....	41,866	7,765		420		49,947	43,094
Kansas.....	75,574	43,775	22,044	160	493	53,519	41,984
Kentucky.....	130,784	63,844	4,583	16,313	219	6,596	20,081
Maryland.....	4,413		600	10			1,500
Michigan.....	4,450	7,445				1,572	3,615
Minnesota.....	169,929	96,809		5,697	5,031	94,453	42,666
Missouri.....	233,215	408,327	1,531	2,354	10,374	301,463	106,419
Montana.....	7,628						333
Nebraska.....	1,507	1,033				12,926	28,645
New Jersey.....	375					540	
New York.....	168,569	37,355	3,080	2,574	315	83,198	63,526
Ohio.....	102,109	31,133		624	180	27,675	430,789
Oklahoma.....	4,850	1,000				4,459	35,889
Pennsylvania.....	104,930	1,410	124,521	2,128	1,250	2,283	709
Tennessee.....	16,854	4,432		3,310		4,085	26,298
Texas.....	28,601	17,540	365	60		86,241	14,581
Utah.....	29,785						
Vermont.....	5,412						
Virginia.....	715	129	15		7	3,000	
Wisconsin.....	96,161	15,832	26,807	20,573	13,902	97,689	65,063
Wyoming.....						700	
Total.....	2,570,326	2,226,942	188,680	214,140	41,343	1,228,445	1,082,234

TABLE 87.—LIMESTONE PRODUCTION, BY STATES AND USES, 1909.—*Continued.*

State or Territory.	Crushed stone.			Flux.	Sugar. factories.	Other.	Total.
	Road making.	Railroad ballast.	Concrete.				
Alabama.....	\$60,452	\$5,521	\$16,825	\$512,585		\$1,512	\$700,642
Arizona.....							(a)
Arkansas.....	9,126	340	4,284				112,468
California.....	138,962		4,554	29,904	\$92,233	5,875	283,869
Colorado.....	100			267,806	86,888	342	355,136
Connecticut.....				1,933		3,000	b 5,023
Florida.....	4,150	2,569	12,343			8,755	c 49,856
Georgia.....	749	14,091	3,103	15,696			34,593
Hawaii.....							(d)
Idaho.....							(d)
Illinois.....	1,216,759	422,859	1,249,783	714,631	1,971	36,589	4,234,927
Indiana.....	627,289	54,086	54,449	190,809	982	95,972	3,749,239
Iowa.....	116,246	16,329	246,054		675	2,881	525,277
Kansas.....	155,294	257,654	207,405	493		28,940	892,335
Kentucky.....	273,411	291,266	47,364	10,804		38,609	903,874
Louisiana.....							(e)
Maine.....							(f)
Maryland.....	108,630	20,071	61,201			1,514	197,939
Michigan.....	132,902	42,445	112,829	91,915	25,845	327,571	750,589
Minnesota.....	80,441	38,329	157,263		6,033	1,658	698,309
Missouri.....	542,904	87,445	339,036	31,075	13,321	33,819	2,111,283
Montana.....			15,400	127,532	3,171		154,064
Nebraska.....	83,147	31,898	118,523	15,000	1,136	15	293,830
New Jersey.....	8,321		8,346	206,435			224,017
New Mexico.....	3,750	107,500	3,150	15,395		11,006	g 140,801
New York.....	750,980	419,489	495,970	343,891		253,406	2,622,353
North Carolina.....							(h)
Ohio.....	1,502,483	332,569	236,619	1,130,082	2,088	223,695	4,020,046
Oklahoma.....	5,491	148,589	243,277			6,500	450,055
Pennsylvania.....	596,023	444,091	489,241	3,165,872		140,767	5,073,825
Rhode Island.....							(f)
South Dakota.....	7,184	12,600	5,400	1,200	22,944		i 49,328
Tennessee.....	276,945	95,665	72,706	87,432		2,222	j 589,949
Texas.....	125,661	3,400	24,260	40,819			341,528
Utah.....				126,915	13,000		169,700
Vermont.....	8,672		4,362	250		143	18,839
Virginia.....	31,076	84,883	8,068	213,444		1,319	342,656
Washington.....	225			31,317		6,727	38,269
West Virginia.....	47,152	294,938	19,865	492,497		9,940	864,392
Wisconsin.....	379,723	79,803	188,395	56,075		7,021	1,047,044
Wyoming.....					21,000	2,646	24,346
Total.....	7,294,248	3,308,430	4,450,075	7,921,807	291,287	1,252,444	32,070,401

a Included in New Mexico.

b Includes Maine and Rhode Island.

c Includes Louisiana.

d Included in South Dakota.

e Included in Florida.

f Included in Connecticut.

g Includes Arizona.

h Included in Tennessee.

i Includes Idaho and Hawaii.

j Includes North Carolina.

CHAPTER X.

MARBLES.

THE term marble is applied by the geologist to limestones which, through the action of heat and pressure, have so changed in texture as to be completely crystalline. In the stone trade, however, marble has a wider meaning, including any limestone which can be made to take a high polish and which, when so polished, will show pleasing color effects. Indeed the term has at times been carelessly applied even to siliceous rocks, a misapplication which entirely robs it of meaning.

Varieties of Marble. — Using the term marble in the sense in which it is applied by the engineer and quarryman, three quite distinct types may be noted.

(a) Highly crystalline marbles showing distinct crystalline structure and fracture. These are usually white, though gray, black, or other markings may be present, scattered over a white ground. Most of the Alabama, Georgia, Vermont, Massachusetts, Connecticut, and southeastern New York marbles are of this type.

(b) Subcrystalline or fossiliferous marbles; in which crystalline structure is rarely very noticeable, the value depending rather on color effect than on texture. Frequently these color effects are gained through the presence of fossils, as often shown in the Tennessee marbles.

(c) Onyx marbles; translucent rocks, showing color banding, due to the fact that they were formed layer after layer by chemical deposition from spring or cave waters.

I. HIGHLY CRYSTALLINE MARBLES.

In a sense, practically all limestones are crystalline, for under the microscope traces at least of crystalline structure can be detected even in the most earthy limestones. But the stones which are here grouped as the highly crystalline marbles are crystalline in a much greater degree, for they are made up entirely of grains of calcite or more rarely dolomite, and the crystalline

character of these component grains is obvious, even without the use of the microscope.

Origin and Character. — The present highly crystalline condition of these marbles is not due to anything in their chemical composition, or to the conditions under which they were originally deposited, but to the effects of the heat and pressure to which they have been subjected since deposition. Originally they were simply limestones of quite ordinary type so far as either composition or structure were concerned, and under normal conditions they would have remained ordinary limestones to this day.

If limestones are heated sufficiently under atmospheric pressure, they will simply be calcined, carbon dioxide being driven off and quicklime remaining. But if the heat be accompanied by intense pressure, sufficient to prevent the evolution of the carbon dioxide gas, the stone will assume a semifluid condition. This condition permits a gradual movement, rearrangement, and recrystallization of the particles of calcite; and if this metamorphism is thorough enough, the final result is the production of a highly crystalline marble.

On a later page in discussing the geological distribution of the highly crystalline marbles, some consideration will be given to the geological conditions which in certain parts of the country favored the formation of these rocks in the fashion above described.

Chemical Composition. — Since the crystalline marbles are merely ordinary limestones physically altered by the action of heat and pressure, they may naturally be expected to show the same range in composition as would a series of normal limestones. If we could make an average analysis of *all* the crystalline limestones of the country, and compare this with an average analysis of *all* the unaltered limestones, this expectation would undoubtedly be verified.

The actual requirements of the stone trade, however, introduce conditions which interfere with this exact agreement in composition of the two groups, as we find them in the market. This is due to the fact that the more impure crystalline marbles, formed by the alteration of siliceous and clayey limestones, are rarely suitable for dressing and polishing. The silica and clay of the original limestone have often, during the metamorphism, com-

bined with some of the lime to form silicate minerals, and the irregular distribution of these minerals through the marble interferes with its dressing and decreases the attractiveness of its appearance.

The result of this condition is that the highly crystalline marbles which have attained success in the market are rarely very impure. A series of marble analyses, therefore, tends to give a higher average lime content than does a series of analyses of ordinary limestones.

TABLE 88. — ANALYSES OF AMERICAN CRYSTALLINE MARBLES.

State.	Location.	Silica.	Alu- mina.	Iron oxide.	Lime car- bonate.	Lime.	Magnesium carbonate.	Magnesia.	Alkalies.	Carbon dioxide.	Water.
Alabama	Wynnette.....	tr.	.....	.....	98.75	.....	.....	0.75	.....	.....	.....
	Colton.....	.....	.....	.....	92.9	.....	4.5	.....	.....	.....	.....
	Inyo County.....	0.60	.....	.....	54.25	.....	44.45	21.79	.....	47.35	.....
Colorado	"	.....	.....	0.02	.....	31.01	.....	.....	.....	.....	.....
	Beulah.....	0.06	.....	0.04	98.00	.....	.....	0.05	.....	.....	.....
Georgia	Marble Hill.....	0.61	0.22	.....	98.96	.....	.....	.....	.....	.....	.....
	Tate.....	0.62	0.25	0.26	97.32	.....	1.60	.....	.....	.....	.....
	"	2.12	.....	0.10	.....	54.06	.....	0.90	.....	42.86	.....
	"	1.62	0.32	0.32	.....	54.41	.....	0.75	.....	43.13	.....
	"	0.35	0.15	0.15	.....	55.00	.....	1.12	.....	44.16	.....
	Jasper.....	0.73	0.35	0.35	.....	32.73	.....	19.37	.....	46.58	.....
	Mineral Bluff....	1.73	0.74	0.74	.....	31.89	.....	19.64	.....	n.d.	.....
	Six Mile Station..	4.23	0.91	0.91	.....	30.42	.....	19.86	n.d.	.....	.....
	White Path.....	1.01	0.78	0.78	.....	31.61	.....	21.06	.....	46.49	.....
	Fannin County....	0.10	0.24	0.24	.....	31.53	.....	21.30	.....	47.26	.....
	Red Clay.....	1.43	3.28	0.28	.....	52.77	.....	0.82	.....	41.85	.....
	Varnell Station..	0.76	0.42	0.42	.....	54.67	.....	1.01	.....	43.49	.....
Maryland	Cockeysville.....	5.57	0.40	0.40	.....	29.08	.....	20.30	.....	44.26	.....
	"	0.44	1.22	1.22	.....	30.73	.....	20.87	.....	45.85	1.22
	"	2.33	.....	.....	.....	29.30	.....	20.81	.....	45.31	0.08
	Texas.....	2.00	.....	.....	.....	52.08	.....	2.38	.....	43.54	.....
	"	1.27	0.14	0.14	.....	31.58	.....	19.64	.....	47.55	.....
	"	0.60	tr.	tr.	98.53	.....	0.87	.....	.....	.....	.....

TABLE 88. — ANALYSES OF AMERICAN CRYSTALLINE MARBLES. — *Continued.*

State.	Location.	Silica.	Alu- mina.	Iron oxide.	Lime car- bonate.	Lime.	Magnesium carbonate.	Magnesia.	Alkalies.	Carbon dioxide.	Water.
Massachusetts	Westfield.....	0.20	.....	0.41	.....	32.77	.....	19.68	.....	46.91	.....
	North Adams....	0.69	.....	0.06	93.86	.....	5.34	.....	.....	.....	0.17
	Alford.....	0.78	.....	0.04	98.43	.....	.....	0.21	.....	.....	.....
	Ashley Falls....	0.28	0.43	0.07	.....	30.03	.....	21.37	0.20	47.42	.....
	Adams.....	0.63	.....	0.55	99.60	.....	0.49	.....	.....	.....	.....
Montana	Sheffield.....	0.38	.....	0.14	98.34	.....	0.50	.....	.....	.....	0.64
	Helena.....	7.88	4.30	0.47	50.12	.....	37.26	.....	.....	.....	.....
	".....	4.45	0.40	0.20	93.12	.....	2.12	.....	.....	.....	.....
Nevada	White Pine Co....	0.60	0.33	0.22	.....	48.58	.....	5.66	.....	44.39	.....
	" ".....	0.40	0.26	0.24	.....	53.69	.....	1.43	.....	43.78	.....
	" ".....	0.28	0.23	0.24	.....	49.56	.....	5.00	.....	44.50	.....
	" ".....	0.50	0.26	0.34	.....	53.69	.....	1.35	.....	43.68	.....
New York	South Dover....	0.70	0.37	0.25	.....	30.63	.....	20.25	0.58	46.66	.....
	Tuckahoe.....	1.33	.....	0.21	.....	30.68	.....	20.71	.....	46.66	0.16
	Ossining.....	0.20	.....	0.23	.....	30.04	.....	22.28	.....	47.14	.....
	Pleasantville....	0.10	0.07	0.11	54.12	.....	45.04	.....	.....	.....	.....
	Gouverneur.....	1.58	.....	0.79	.....	51.45	.....	3.49	.....	42.56	.....
	".....	0.28	0.10	Trace	.....	31.45	.....	20.64	.....	47.38	.....
	".....	1.55	.....	.....	.....	51.08	.....	2.95	.....	44.22	.....
Pennsylvania	".....	1.85	0.23	0.38	92.29	.....	4.28	.....	.....	.....	.....
	King of Prussia..	0.77	0.17	0.54	98.16	.....	.....	0.51	.....	.....	.....
	" ".....	0.58	0.16	0.51	97.71	.....	.....	0.80	.....	.....	0.59
	Dauphin Co.....	1.07	0.14	0.23	95.10	.....	3.96	.....	.....	.....	.....

TABLE 88.—ANALYSES OF AMERICAN CRYSTALLINE MARBLES.—*Concluded.*

State.	Location.	Silica.	Alu- mina.	Iron oxide.	Lime car- bonate.	Lime.	Magnesium carbonate.	Magnesia.	Alkalies.	Carbon dioxide.	Water.
Vermont	Proctor.....	0.63	.....	0.05	96.30	.....	3.06	.....	.....	.....	.....
	"	0.63	0.005	0.03	98.37	.....	0.77	.....	.....	44.02	.....
	"	0.35	.....	0.20	.....	55.00	.....	0.25	.....	43.21	.....
	Danby.....	0.33	0.92	0.12	.....	54.76	.....	0.16	0.03	43.82	.....
	West Rutland ...	0.28	0.30	0.30	.....	55.27	.....	0.28	.....	43.66	.....
	"	0.40	0.20	0.20	.....	55.26	.....	0.15	.....	43.65	.....
Washington	"	0.70	0.15	0.15	.....	55.50	.....	tr.	.....	.....	.....
	Bossburg	2.94	0.49	0.49	.....	31.56	.....	18.56	.....	45.91	.....
	Chewelah.....	23.98	.....	1.40	.....	22.51	.....	16.43	.....	33.61	0.26
	"	17.67	4.61	1.54	.....	30.92	.....	16.32	.....	25.08	.....
	"	17.59	0.48	1.62	.....	26.52	.....	15.46	.....	38.25	.....
	"	15.18	.....	.....	.....	27.69	.....	17.02	.....	40.55	.....
	"	5.28	2.58	1.65	.....	28.83	.....	17.28	.....	44.27	.....
	"	0.82	.....	0.63	.....	32.77	.....	19.02	.....	46.73	.....
	"	0.17	.....	.....	.....	43.24	.....	10.78	.....	45.75	.....
	Colville.....	1.89	.....	.....	.....	43.60	.....	10.05	.....	44.63	.....
	"	0.98	.....	.....	.....	53.96	.....	1.25	.....	43.76	.....
	"	3.12	.....	0.93	.....	52.04	.....	0.67	.....	43.22	.....
	"	2.61	.....	.....	.....	53.68	.....	0.76	.....	42.89	.....
	"	0.82	.....	tr.	.....	54.81	.....	0.70	.....	43.56	.....
	"	0.87	.....	tr.	.....	55.11	.....	0.21	.....	43.77	0.05
	"	3.49	tr.	0.24	.....	51.54	.....	1.11	.....	42.36	0.10
	"	0.91	.....	.....	.....	31.80	.....	20.64	.....	46.64	.....
	"	0.98	.....	.....	.....	30.08	.....	22.21	.....	46.70	.....
	Marble.....	23.32	.....	0.19	.....	42.46	.....	0.32	.....	33.44	0.05
	Ryan.....	1.10	.....	.....	.....	53.96	.....	1.60	.....	43.27	.....
	Valley.....	0.13	.....	.....	.....	54.95	.....	0.54	.....	44.22	.....
	"	10.47	1.85	1.13	.....	32.66	.....	15.03	.....	38.19	0.67

TABLE 89. — PHYSICAL PROPERTIES OF AMERICAN CRYSTALLINE MARBLES.

State.	Locality.	Tested by	Specific gravity.	Weight per cubic foot.	Absorption.	Size cube.	No. tests.	Compressive strength.		
								Minimum.	Average.	Maximum.
Arizona	Bowie.....	U. S. Geol. Survey ...	2.709	168.9	0.001	Inches. 2	3	10,430	11,310	12,000
	Colton.....	Univ. California.....	2.75	172.1	.....	.....	.....	17,095	9,350 17,440	17,783
California	Inyo Co.....	.....	.....	.....	.....	.....	.....	.....	29,000	.....
	Canaan.....	Gillmore.....	.....	.....	.....	.....	.....	.....	5,812	.....
Connecticut	Tate.....	Georgia Geol. Survey	2.763	172.6	0.004	1	3	13,100	13,400	13,900
	"	"	2.707	169.1	0.005	1	3	12,244	12,660	13,200
Georgia	Marble Hill.....	"	2.717	169.8	0.008	1	3	10,204	10,760	11,400
	"	"	2.734	171.8	0.007	1	3	10,800	11,000	11,300
Massachusetts	Tate	Watertown Arsenal...	.....	.....	.....	6	3	10,642	11,230	12,078
	Ashley Falls.....	Ricketts & Banks....	.....	.....	.....	.....	.....	20,110	20,655	21,200
Nevada	Egremont.....	"	.....	.....	.....	.....	.....	.....	10,910	.....
	Adams.....	Watertown Arsenal...	.....	.....	.....	.....	.....	.....	13,347	.....
	Lee.....	"	.....	.....	.....	.....	.....	.....	18,047	.....
	Westfield.....	"	.....	.....	.....	.....	.....	.....	21,820	.....
	White Pine Co....	U. S. Geol. Survey...	2.663	166.0	0.50	4	1	.....	16,780	.....
	"	"	2.656	165.6	0.57	4	1	.....	16,995	.....
	"	"	2.696	168.1	0.18	4	1	.....	20,145	.....
	"	"	2.705	168.4	0.16	4	1	.....	18,355	.....

TABLE 89. — PHYSICAL PROPERTIES OF AMERICAN CRYSTALLINE MARBLES. — *Concluded.*

State.	Locality.	Tested by	Specific gravity.	Weight per cubic foot.	Absorption.	Size cube.	No. of tests.	Compressive strength.		
								Minimum.	Average.	Maximum.
New York	Gouverneur.....	Watertown Arsenal.....	.....	170.0	.....	Inches. 6	.....	.....	12,692	.....
	"	"	.....	.....	.....	4	.....	23,070	24,160	25,250
	South Dover.....	Columbia Univ.....	2.86	.....	0.267	2	3	17,401	19,040	20,882
	Tuckahoe.....	Gillmore.....	2.875	179.7	.....	2	2	12,050	12,500	12,950
Pennsylvania	"	"	2.800	175.0	.....	2	2	13,594	13,650	13,711
	Pleasantville.....	"	.....	.....	.....	.....	.....	.....	22,383	.....
	King of Prussia.....	.....	2.727	.....	.....	.....	.....	.....	.....	.....
	Fort Croghan.....	Rock Island Arsenal.....	2.679	167.0	0.004	.....	.....	.....	13,782	.....
Texas	San Saba Co.....	Univ. of Texas.....	2.81	166.7	0.006	1	.....	.....	10,330	.....
	Brewster Co.....	"	2.74	170.3	0.002	1	.....	.....	10,420	.....
	Dorset.....	Gillmore.....	2.683	167.8	.....	2	1	.....	8,670	.....
Vermont	.....	Watertown.....	.....	.....	.....	6	.....	.....	13,400	.....
Washington	Colville.....	Washington Univ.....	2.724	179.3	0.10	2	1	.....	11,600	.....
	"	"	2.740	170.2	0.69	2	2	14,360	15,180	16,000
	"	"	2.876	178.2	0.17	2	2	15,420	18,010	20,600
	"	"	2.875	176.4	0.10	2	2	23,200	23,600	24,000
	"	"	2.813	173.7	0.16	2	3	11,870	12,785	13,600
	"	"	2.873	178.0	0.16	2	1	.....	21,500	.....
	Chewelah.....	"	2.817	175.0	0.06	2	3	14,560	17,310	20,950
Northport.....	Ione.....	"	.....	.....	.....	2	2	19,830	22,170	24,510
	"	"	2.872	177.6	0.23	2	2	15,420	19,290	23,160
	"	"	.....	.....	.....	2	2	11,700	12,345	12,990

Production of Marble in the United States.— The following tables, quoted from those issued annually by the United States Geological Survey, give statistics concerning the American marble industry for a series of years. It is to be noted that under the head of marble these tables include the comparatively unimportant amounts of serpentine, "verd antique marble," etc., produced in the United States.

TABLE 90. — MARBLE PRODUCTION OF THE UNITED STATES, 1899-1909.

Year.	Value.	Year.	Value.
1899	\$4,011,681	1905	\$7,129,071
1900	4,267,253	1906	7,582,938
1901	4,965,699	1907	7,837,685
1902	5,044,182	1908	7,733,920
1903	5,362,686	1909	6,548,905
1904	6,297,835	1910	6,992,779

TABLE 91. — MARBLE PRODUCTION, BY STATES AND USES, 1908-1909.

1908.									
State or Territory.	Rough.			Dressed.					Total.
	Build-ing.	Monu-mental.	Other uses.	Build-ing.	Orna-mental.	Orna-mental.	Interior decora-tion.	Other uses.	
Alabama.....	\$898		\$2,500	\$113	\$4,650		\$77,000	\$33,419	<i>a</i> \$118,580
Alaska.....	38,500	\$1,688		45,000	7,200	\$500	10,600	400	<i>b</i> 103,888
California.....	8,100	1,250					50,782	276	60,408
Colorado.....									<i>c</i>
Georgia.....	368,981	342,000	78,800	100,000	17,500			9,000	916,281
Kentucky.....									<i>d</i>
Maryland.....	1,050	8,425	4,652	65,190					<i>e</i> 79,317
Massachusetts.....	1,888			110,856	19,786		34,660	8,458	175,648
Missouri.....									<i>d</i>
New Mexico.....									<i>c</i>
New York.....	74,538	56,200	30,421	472,407	53,292		20,000		706,858
North Carolina.....									<i>f</i>
Pennsylvania.....	13,444			54,803	9,000	7,000	15,000	3,500	102,747
Tennessee.....	83,764	10,755	37,575	78,440	17,590		551,449	10,660	790,233
Utah.....									<i>c</i>
Vermont.....	156,325	134,036	190	1,402,629	1,714,408	18,006	1,184,259	70,107	4,679,960
Total....	747,488	554,354	154,138	2,329,438	1,843,426	25,506	1,943,750	135,820	7,733,920

a Includes Kentucky and Missouri.

b Includes Colorado, New Mexico, and Utah.

c Included in Alaska.

d Included in Alabama.

e Includes North Carolina.

f Included in Maryland.

TABLE 91.—MARBLE PRODUCTION, BY STATES AND USES, 1908-1909. — *Continued.*

State or Territory.	Rough.			Dressed.					Total.
	Build- ing.	Monu- mental.	Other uses.	Build- ing.	Monu- mental.	Orna- men- tal.	Interior decora- tion.	Other uses.	
Alabama.....	\$39,825	\$22,783	\$6,900	\$12,000			\$129,554	\$1,400	<i>a</i> \$212,462
Alaska.....	42,100	300	500		\$4,000				<i>b</i> 46,900
Arizona.....									<i>c</i>
California.....	83,887	563	4,942						89,392
Colorado.....	190,600	175			2,045		295,491		<i>d</i> 488,311
Georgia.....	528,454	25,000	15,745	156,000	26,250			15,000	766,449
Kentucky.....									<i>e</i>
Maryland.....									<i>e</i>
Massachusetts.....	23,759	900	1,424	16,500	53,372	\$695	134,561	12,500	243,711
New Mexico.....	500	2,950	940	1,000					<i>f</i> 5,390
New York.....	64,400	49,950	32,641	135,919	88,559		31,260		402,729
North Carolina.....									<i>e</i>
Oregon.....									<i>e</i>
Pennsylvania.....	29,108	1,700	5,751	107,978	7,500		34,000		186,037
Tennessee.....	130,315	4,625	35,575	36,478	4,275		394,973	7,500	613,741
Texas.....									<i>c</i>
Utah.....									<i>g</i>
Vermont.....	455,300	462,580	66,144	827,144	998,671	24,000	537,944	122,000	3,493,783
Washington.....									<i>h</i>
West Virginia.....									<i>e</i>
Total.....	1,588,248	571,526	170,562	1,293,019	1,184,672	24,695	1,557,783	158,400	6,548,905

a Includes Kentucky, Maryland, North Carolina, and West Virginia.

b Includes Washington.

c Included in New Mexico.

d Includes Oregon and Utah.

e Included in Alabama.

f Includes Arizona and Texas.

g Included in Colorado

h Included in Alaska.

The following table shows the various uses to which the marble quarried in 1904, 1905, 1906, 1907, 1908, and 1909 was put:

TABLE 92.—DISTRIBUTION AND VALUE OF OUTPUT OF MARBLE, 1904-1909, AMONG VARIOUS USES.

Use.	1904.	1905.	1906.	1907.	1908.	1909.
Sold by producers in rough state	\$2,599,052	\$2,987,542	\$1,795,169	\$1,697,891	\$1,455,980	\$2,330,336
Dressed for building.....	988,671	1,168,450	1,559,925	1,905,145	2,329,438	1,293,019
Ornamental purposes.....	21,554	13,643	44,523	25,050	25,506	24,695
Dressed for monumental work..	1,211,389	1,170,279	2,214,872	2,044,000	1,843,426	1,184,672
Interior decoration in buildings..	1,257,963	1,682,651	1,722,445	1,900,952	1,943,750	1,557,783
Other uses.....	219,206	106,506	246,004	264,647	135,820	158,400
Total.....	6,297,835	7,129,071	7,582,938	7,837,685	7,733,920	6,548,505

Reference List on Crystalline Marbles. — The following list contains the principal publications dealing with the subject of

marbles in general, and with the crystalline marbles in particular.

General treatise:

Burnham, S. M. The history and uses of limestones and marbles, 392 pp. Boston, 1882.

Alabama:

Byrne, P. Marble formations of the Cahaba River, Alabama. Eng. & Min. Jour., vol. 72, p. 400. 1901.

Arizona:

Paige, Sydney. Marble prospects in the Chiricahua Mountains, Arizona. Bull. 380, U. S. Geol. Sur., pp. 299-311. 1909.

California:

Jackson, A. W. Building stones (of California). 7th Ann. Rep. Cal. State Min., pp. 206-217. 1888.

Anon. Marbles of California. Bull. 38, Cal. State Min. Bureau, pp. 95-114. 1906.

Colorado:

Lakes, A. Building and monumental stones of Colorado. Mines and Minerals, vol. 22, pp. 29, 30. 1901.

Connecticut:

Ries, H. The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut. 17th Ann. Rep. U. S. Geol. Sur., pt. 3, pp. 795-811. 1896.

Georgia:

McCallie, S. W. A preliminary report on the marbles of Georgia. Bull. 1, Ga. Geol. Sur., 92 pp. 1894.

Maryland:

Matthews, E. B. An account of the character and distribution of Maryland building stones. Reports Md. Geol. Sur., vol. 2, pp. 125-241. 1898.

Massachusetts:

Ries, H. The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut. 17th Ann. Rep. U. S. Geol. Sur., pt. 3, pp. 795-811. 1896.

Whittle, C. L. The building and road stones of Massachusetts. Eng. and Min. Jour., vol. 66, pp. 236, 237. 1898.

Nevada:

Darton, N. H. Marble of White Pine County, Nevada. Bull. 340, U. S. Geol. Sur., pp. 377-380. 1908.

New York:

Brinsmade, R. B. Marble quarrying of Gouverneur, N. Y. Eng. and Min. Jour., Oct. 21, 1905, pp. 728-730.

Eckel, E. C. The quarry industry in southeastern New York. 20th Ann. Rep. N. Y. State Museum, pp. 141-176. 1902.

Vermont:

Perkins, G. H. Report on the marble, slate, and granite industries of Vermont. 68 pages, Rutland. 1898.

Perkins, G. H. Marble (in Vermont). Rep. Vt. Geol. for 1899-1900, pp. 38-57. 1900.

Perkins, G. H. Marble (in Vermont). Rep. Vt. Geol. for 1901-1902, pp. 40-44. 1902.

Washington:

Shedd, S. Marble and serpentine deposits of Washington. Ann. Rep. for 1902, Wash. Geol. Sur., pp. 75-133. 1903.

II. FOSSILIFEROUS OR SUBCRYSTALLINE MARBLES.

Under this heading are included limestones which, though not highly crystalline, possess sufficiently close texture to take a good polish, and at the same time show attractive color effects. The well-known Tennessee marbles are the best examples of this type of stone.

Origin and Character. — Since the fossiliferous or subcrystalline marbles are simply ordinary limestones, so far as origin is concerned, nothing can be added here to the discussion of the origin of limestones which has been presented in Chapter IX. The only points of difference which require further consideration are those connected with the color and texture of the subcrystalline marbles.

So far as texture is concerned, the stone is necessarily close-grained, free from chert or clayey matter, and susceptible to at least a fair polish. Distinct calcite crystals are not visible, but the groundmass of the stone is crystalline and not earthy in texture.

In order to be salable, the subcrystalline marbles must be either of a particularly attractive or desirable solid color, or they must show attractive contrasting colors. The first type is rare, the only color in which the subcrystalline marbles can excel the crystalline marbles being black. The second type, in which contrasting colors are present, is well-exemplified by the Tennessee marbles. In this second type much of the color effect is often due to the fact that the ground-mass of the stone is of a different color from the shells or other fossils which it contains.

Chemical Composition. — In chemical composition the subcrystalline marbles can of course show little of special interest. Since the presence of much silica or clayey matter would commonly interfere with polishing, the fossiliferous marbles which reach the market are usually fairly pure carbonate rocks.

The following analyses of subcrystalline marbles will serve to give some idea of their range in chemical composition.

TABLE 93. — ANALYSES OF AMERICAN SUBCRYSTALLINE MARBLES.

	1	2	3	4	5	6	7
Silica.....	0.76	1.43	4.23	0.17	0.13	0.07	0.23
Alumina }	0.42	3.28	0.91	{ 0.04	tr.	0.21	0.16
Iron oxide }				{ 0.23	0.26		
Lime.....	54.67	52.77	30.42	55.47	55.32	55.12	55.87
Magnesia.....	1.01	0.82	19.86	0.30	0.21	0.51	0.15
Carbon dioxide.....	43.49	41.85	n. d.	43.63	43.51	43.98	43.47
Water.....				0.21	0.13		

1. Gray marble, Varnell station, Whitfield County, Georgia; W. H. Emerson, analyst; Bull. 1, Georgia Geol. Sur., p. 87.
2. Brown marble, Red Clay P. O., Whitfield County, Georgia; W. H. Emerson, analyst; Bull. 1, Georgia Geol. Sur., p. 87.
3. Black marble, Six Mile Station, Floyd County, Georgia; W. H. Emerson, analyst; Bull. 1, Georgia Geol. Sur., p. 87.
4. Marble, near Knoxville, Tenn.; L. G. Eakins, analyst; Bull. 168, U. S. Geol. Sur., p. 258.
5. Marble, Hawkins County, Tenn.; A. L. Colby, analyst; 18th Ann. Rep. U. S. Geol. Sur., pt. 5, p. 983.
6. Marble, near Knoxville, Tenn.; Agric. Exp. Station, analysts; Bull. 2D, Tenn. Geol. Sur., p. 22.
7. Marble from Meadows quarry, Blount County, Tenn.; G. S. Jamieson, analyst; Bull. 2D, Tenn. Geol. Sur., p. 22.

Geological Distribution. — Geological age is of interest in the present connection only from the fact that the geological history of any limestone must necessarily have had some effect upon its texture and structure. Subcrystalline marbles may be found in limestone formations of almost any geological period, but owing to the fact just stated certain formations are more likely to yield them than others.

In the eastern and central United States, for example, the Cambrian and Silurian rocks were involved in the earth movements which gave rise originally to the mountain ranges which parallel our Atlantic coast. The later rocks — Devonian and Carboniferous — were rarely involved in the folding and metamorphism which accompanied these movements. In consequence, the areas of Cambrian, Ordovician, and Silurian limestones which border the Adirondack and Appalachian ranges are apt to

show a certain degree of metamorphism everywhere. Where the metamorphic effects were intense, highly crystalline marbles were developed, as noted on preceding pages. But even where the metamorphism did not go to the extreme of causing entire recrystallization of the limestones, there is an evident increase in their density and compactness as compared, for example, with entirely unaltered Carboniferous limestones.

Geographic Distribution. — The earliest worked subcrystalline marbles in the United States were those at Hudson, Glens Falls, and Lockport, New York. These were all of different type and age, the Glens Falls stone being a bed in the Trenton formation, the Lockport stone coming from the Niagara group, while the Hudson marble was found in the Lower Helderberg group. All three of the groups named are Silurian in age, in the broader sense in which the term Silurian was long used.

The Tennessee marbles, which are by far the best known and most important American examples of the subcrystalline type, occur as beds in the Chickamauga formation. This is of Ordovician age, and corresponds approximately to the Trenton formation of New York, which once furnished similar marbles at Glens Falls and elsewhere. These marble beds of the Chickamauga formation occur not only in eastern Tennessee but in the adjoining portions of Virginia and Georgia. In these latter states, however, they have never been extensively developed.

Production of Subcrystalline Marble. Owing to the development of these deposits of subcrystalline marble, Tennessee ranks at present third among the marble producing states, being surpassed in value of annual output only by Vermont and Georgia. Since all the marble output of Tennessee is of the subcrystalline type, and since the relatively unimportant amounts of subcrystalline marble produced in other states cannot be accurately determined, the data as to production given below will be confined to the output of Tennessee.

TABLE 94.—ANNUAL PRODUCTION OF SUBCRYSTALLINE MARBLE, 1905-1909.

1905.....	\$582,229
1906.....	635,821
1907.....	688,148
1908.....	790,233
1909.....	613,741

In the years noted the production of subcrystalline marble in the United States, as indicated by the production of Tennessee, ranged between eight per cent and ten per cent of the total output of all kinds of marble in the United States.

The distribution of the total Tennessee output by uses, for the years 1908 and 1909, was as follows:

Use.	1908.	1909.
Sold rough, for		
Building stone.....	\$83,764	\$130,315
Monumental stone.....	10,755	4,625
Other purposes.....	37,575	35,575
Sold dressed, for		
Building stone.....	78,440	36,478
Monumental.....	17,590	4,275
Interior decoration.....	551,449	394,973
Other purposes.....	10,660	7,500
Total Tennessee output.....	\$790,233	\$613,741

Reference List on Fossiliferous Marbles. — The following brief list includes the titles of the more important publications referring to the Tennessee marbles, which are the only extensively developed fossiliferous marbles in the United States. The report by Gordon is by far the most detailed and important one in the list.

- Cotton, H. E., and Gattinger, A. Tennessee building stones. Vol. 10, Reports 10th U. S. Census, pp. 187, 188. 1884.
 Gordon, C. B. The marbles of Tennessee. Bull. 2D, Tenn. Geol. Sur., 33 pp. 1911.
 Keith, A. Tennessee marbles. Bull. 213, U. S. Geol. Sur., pp. 366-370. 1903.
 Willis, B. The marbles of Hawkins County, Tennessee. School of Mines Quarterly, vol. 9, pp. 112-123. 1888.

ONYX MARBLES.

Origin and Character. — The onyx marbles are deposits of relatively pure calcium carbonate, deposited by waters which have carried it in solution. The deposition may take place at the surface, around the exits of springs, or in caves along the course of flow of underground waters.

During the course of this deposition, which is usually a slow and not necessarily continuous process, changes may take place

in the composition of the dissolved material contained in the water; and very slight differences in the amounts of iron oxide, organic matter, or other coloring material which is precipitated along with the calcium carbonate will be sufficient to produce the color banding which is so characteristic and desirable a feature of the onyx marbles.

Uses and Production. — The onyx marbles are of practically no structural value, and are used entirely for decorative purposes. They are to be compared, therefore, with serpentine and some of the more purely decorative crystalline marbles.

No data are available to determine, even approximately, the output of onyx marbles and allied products in the United States. In the statistical reports of the United States Geological Survey, such output, whatever it may amount to, is included in the production of marble and limestone.

It is known that onyx marbles are produced commercially in California, Arizona, New Mexico, and Utah. In the states of Kentucky, Tennessee, Virginia, and West Virginia some attention has been paid to the quarrying or mining of the cave marbles, but no steady commercial production seems to have resulted as yet in any of these states.

Reference List on Onyx Marbles. — The publications noted in the following brief list are of interest as referring to the onyx marbles. Of those listed, Merrill's report of 1894 is by far the most important and complete.

- De Kalb, C. Onyx marbles. Trans. Am. Inst. Min. Eng., vol. 25, pp. 557-569. 1896.
- De Kalb, C. Onyx marbles. 20th Ann. Rep. U. S. Geol. Sur., pt. 6, pp. 286-291. 1899.
- Gorby, S. S. The onyx deposits of Barren County, Kentucky. Eng. & Min. Jour., vol. 67, pp. 707, 708. 1899.
- Merrill, G. P. The onyx marbles; their origin, composition, and uses, both ancient and modern. Rep. U. S. National Museum for 1893, pp. 539-585. 1894.
- Merrill, G. P. A consideration of some little-known American ornamental stones. Stone, vol. 19, pp. 225-230. 1899.
- Anon. Onyx marbles of California. Bull. 38, Cal. State Min. Bureau, pp. 111-114. 1906.

CHAPTER XI.

FIELD EXAMINATION AND VALUATION OF STONE PROPERTIES.

THE valuation of a stone property will usually necessitate a careful field examination, some far less important laboratory work, and finally a study of the commercial conditions which affect values. As a matter of fact, the last of these is by far the most important, though it is rarely even referred to in books on building stones.

In the present chapter the field examination of stone properties will be taken up, followed by some consideration of business conditions in the stone industry. Laboratory tests will be treated in a later chapter.

THE FIELD EXAMINATION OF STONE PROPERTIES.

Scope of Reports. — Reports upon stone properties or quarries naturally fall into two quite distinct classes, with different aims and requirements. One class would include the detailed expert examination of the property as a commercial proposition, looking toward placing the stone on the regular market. The other class would include the much less detailed report necessary when stone from a certain property or quarry is offered for an important engineering work. In this latter case the question before the engineer is simply whether or not the quarry can reasonably be expected to supply a sufficient quantity of stone, of quality satisfactory for the proposed work. In the former case, where the expert report will probably be used as a basis for exploiting the property, many other features of the proposition will require careful examination; and a complete report of this class should include sufficient data to answer the following questions:

- (1) Is the stone of such character that it can find a market when placed in competition with stone from existing quarries?
- (2) Is there sufficient quantity of good stone to justify the investment necessary for lands and plant?

(3) Can the stone be quarried and transported cheaply enough to compete with existing quarries?

The property to be examined may be a quarry, either working or abandoned, or it may consist entirely of undeveloped land. In the first case there will be little difficulty in seeing enough of the stone to form a good idea of its character, extent, etc., and actual exploratory work will usually be unnecessary. Occasionally, however, drilling or trenching will be required, even when a quarry has been opened on the land, before a safe estimate can be made as to the quantity of stone available. When the land is entirely undeveloped, the case becomes more serious. Road cuts, railroad cuts, and stream banks must then be carefully examined; and hillsides will often furnish fairly good natural outcrops. In some cases this will be sufficient, but if the proposed investment is heavy it will be best to drill or trench. The choice between these two methods of examination will depend largely on the kind and structure of the rock. In limestones or sandstones dipping at a high angle, trenching *across* the strike of the beds will be least expensive, and more satisfactory than drilling. For granites also, which show no bedding, trenching is best. But if the rocks are limestones or sandstones lying horizontally, or nearly so, drilling will usually be more satisfactory than trenching; and for roofing slates this method is always to be preferred. A small face can also be opened up at the point which seems best suited for the site of the proposed quarry, and information as to the actual working properties of the stone can thus be obtained.

Exploration required. In nine cases out of ten, however, the engineer called to report on a stone property will find that little exploratory work is required. Building stone is so common a product that a land owner rarely becomes enthusiastic enough about it to ask for an expert opinion unless the rock has been quarried on his own or a neighboring property, or else shows naturally in some particularly imposing cliff.

In examining a stone property, there are practically only two cases in which it will be advisable to go to the expense of using the diamond drill. These are: (1) in a slate deposit, and (2) in a marble bed dipping at a high angle — 45 degrees or more. In both these cases the actual quarries are apt to take the form of deep narrow cuts, and for this reason it will pay to determine the

character of the rock to some depth. But in all other cases a core drill will give little information of value. Stone can rarely be profitably worked by mining, so that a drill core showing that a good bed of stone occurs at some considerable depth is hardly of much service. In a granite quarry of such limited areal extent that deep workings seem probable, it may pay to take out a few 40- or 50-foot cores in order to be sure that the color and texture of the stone will continue to be satisfactory, but in most cases drilling a stone prospect is unnecessary and unadvisable.

The case is, of course, very different when the stone is to be used for some purpose in which its exact chemical composition is of importance. If a sandstone is to be used for glass, or a limestone for cement, core drilling is practically the only means of securing good samples for analysis of all the beds of the rock. But this is a case which hardly enters into the field of the present volume.

Schedule for Notes. The following form was devised for use on the United States Geological Survey, as a general guide for securing the proper kind and amount of data regarding developed stone properties. Though this form was planned for a special purpose, it will serve as a useful framework on which to hang brief notes on the principal points to be observed in examining either a quarry or an entirely undeveloped property. It will be seen that many of these points can be disregarded if the report is to be merely on the question of whether or not the property can supply enough good stone for a given engineering work. But for a complete report, to be used as a basis for valuing or financing the property, all these points must be considered. A few of the questions, of course, can apply only to a working quarry.

SCHEDULE FOR QUARRIES.

1. Name and address of owner.....
2. Name and address of lessee, if any.....
3. Location of quarry.....
4. Area of quarry, maximum and average depths.....
5. Amount and character of stripping.....
6. Drainage conditions.....
7. Machinery, hoists, compressors, drills, channelers, steam shovels, pumps..
8. Methods of hoisting.....
9. Methods of transportation.....
10. Number of men and teams worked.....
11. Kind of rock quarried.....

12. Geologic age.
13. Strike and dip.
14. Thickness of beds (for sediments).
15. Distribution and spacing of joints (for granites, etc.).
16. Segregations, dikes, cleavage (for slates), etc. (for granites).
17. Color, texture, and composition of rock.
18. Visible impurities.
19. Discoloration or weathering on natural exposed surface.
20. Chemical composition: name and address of analyst.
21. Uses. (a) for limestone; dimension stone, rough stone, road metal, railway ballast, lime, flux, carbonic acid, pottery, natural cement, Portland cement.
- (b) for sandstone; building stone, grindstones, paving, and flagging, glass sand.
- (c) for granites, etc.; dressed building stone, monumental, rough stone, paving, etc.
22. Annual production.
23. Sales prices per cubic foot or other customary measure.
24. Total amount invested.
25. Date of opening quarry.
26. Principal market points.
27. Principal buildings or works supplied.

Grain. — Among the principal points to be noted are size and regularity of grain particularly in granites and sandstones.

It should, however, be borne in mind that the terms “fine-grained” and “coarse-grained,” as applied to building stones, are entirely comparative, and depend largely on the kind of rock under consideration. A granite, for example, whose constituent minerals averaged $\frac{1}{4}$ inch in diameter would be a rather fine-grained rock, *for a granite*. But a sandstone whose grains were of that size would properly be called a very coarse-grained stone; and in a limestone or marble grains of this diameter would be exceptionally large.

It would be better, though a little more troublesome, to discard such vague comparative terms when describing a building stone, and to state the approximate average diameter of its constituent particles in fractions of an inch.

In addition to the *average* size of grain, *variations* in size are to be noted. In most building stones the grains, in any given slab, will be of about the same size. But in some igneous rocks — as the porphyries, for example — the mass of the rock will consist of a very fine-grained groundmass, scattered through which are large crystals, usually of the least fusible constituent. In sandstone, also, a similar irregularity of grain is often observable, while in the limestones, marbles, and slates such variations in size of grain are exceptional.

Color. — In regard to color, the points to be considered are its tint, its permanence, and its regularity, as all three are matters of commercial importance.

The tint of the stone will, of course, be obvious enough when a fresh surface is examined. In describing it, comparisons may be made with that of well-known stones already on the market, for such comparisons will often convey a clearer idea than any simple statement.

The color of an absolutely freshly broken face of the stone should be compared with that shown by a natural weathered surface in order to determine the probable permanence of the tint. If the stone has been quarried and used at some known date in the past, search should be made for old buildings or old blocks in the quarry, as these will give a definite idea as to the color changes which are likely to occur in a given tint.

In sedimentary rocks, different colors will probably be shown by different beds, but in any given bed the color should be practically uniform throughout. Any differences which exist between the color of different beds, or of different parts of the same bed, should be noted. In granites and allied igneous rocks, it is often observed that irregular blotches occur at intervals, destroying the uniformity of the color. In all these cases, an estimate should be made of the ease or difficulty of supplying a large amount of stone of some particular tint; for most contracts for buildings will contain some requirement in this line.

Joints. — The jointing of the rock is one of the principal features to be noted, for usually it determines the size and shape of the largest blocks that can be quarried. Most igneous rocks, and many sedimentary deposits, will show three intersecting systems of joint planes, though they may be only apparent on a very close examination. Frequently one of these systems is nearly horizontal, and the other two close to vertical. The horizontal joint plane, if present, requires no special description, but for planes vertical or even slightly inclined to the horizon the direction and amount of dip of each system should be recorded. This done, the regularity and amount of the spacing between the successive joints of each system is to be noted, and finally the comparative importance of the various systems is considered.

The following example gives a typical case of a description

covering the points just noted: "The granite is cut by three series of joints. The first series is by far the strongest, and is practically horizontal, its planes being spaced from 3 to 6 feet apart. The second series in order of importance is almost vertical, striking N. 30° E. and dipping 80° N. W.; with the spacing varying from 6 to 15 feet, the former being nearer the average. The third series is comparatively weak, showing only in certain parts of the quarry, its planes strike N. 45° W., and dip 72° N. E., while its spacing, where the planes are visible, is from 6 to 10 feet apart."

Impurities. — The presence of iron pyrite, nodules or bands of chert, iron stains, pockets of clay, etc., is to be looked for with care. This is particularly important when the stone under consideration is a marble, a limestone, or a slate.

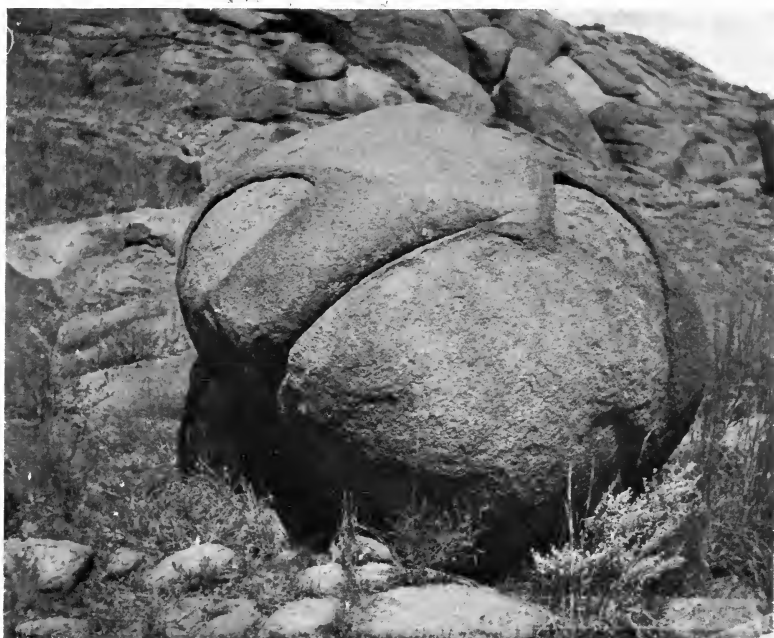


Fig. 22. — Concentric weathering of granite. (Photo by J. E. Taff.)

Segregations and Dikes. — Granite outcrops or quarry faces frequently show lenticular or irregular segregations of the dark-colored mineral constituents of the rock. Similar concentrations

of coarse-grained feldspar and quartz also occur. Often the outcrop or quarry is crossed by a dike or band of some other igneous rock.

Weathering.— The examination of old buildings, and of natural exposures of the stone under test, are valuable aids to a determination of its probable durability. Field examination requires, however, a good knowledge of the geological history



Fig. 23. — Boulders showing decay of basic igneous rock. (Photo by E. C. Eckel.)

of the area in which the quarry occurs, as the degree to which a natural exposure of the stone has disintegrated will depend not only on the character of the stone, but on the length of time it has been exposed to the weather. Rock areas in New York and New England are rarely weathered deeply, as this district was swept clean during the Glacial period, while rocks of similar type and equal durability in the Southern States may be covered by from 50 to 150 feet of material resulting from their own disintegration.

VALUATION OF STONE PROPERTIES.

In the present section attention will be directed to certain aspects of the stone industry which have not heretofore been discussed in print, but which are of great and increasing interest to the engineer.

The Engineer's Responsibility for Flotations. — In the present condition of the stone trade any one, whether experienced or not, is likely to be called upon to examine and report on stone property. If the matter ended there, this condition would affect no one except the owner; and the present section would not need to be written, for the preceding portion of this chapter covers the principal points which must be considered in a merely technical examination of a quarry property. But there are indications that the stone industry is now beginning to develop in a larger way, and there is the certainty that, if an engineer's name has any value whatever in banking or business circles, his report will be used as a guarantee, not only of the technical soundness of the proposition, but also of its financial soundness. It is one thing to say that a stone is attractive in appearance, that it is probably durable, that it can be quarried at reasonable cost, and that it exists in a certain tonnage on a given property. It is quite another thing to recommend, even by implication, the purchase of securities issued against this same property.

This difference in attitude should of course be obvious, and there should be no difficulty in distinguishing between the two cases. But as a matter of fact if an engineer of any standing reports on a new enterprise it is almost impossible for him to word his report so carefully as not to have it accepted as a guarantee, not only of technical conditions, but of the financial security of the enterprise. Engineers are not the only persons likely to encounter this difficulty, and the only reason for their greater care is that the public expects more from them. By this time the public has become accustomed to seeing admirals, clergymen, generals, and senators appear as sponsors for oil companies, mining promotions, and all sorts of swindles — and it looks on this in the charitable conviction that of course they can know nothing about these businesses and are simply foolish. With an engineer, however, the case is different, and the view taken is usually far from charitable.

Present Status of the Stone Industry. — Unlike most other American industries, the stone trade is still largely in the hands of individuals, or of relatively small firms or corporations. The data presented below show that in 1902, the latest date for which statistics on this point were available, the various sections of the stone trade showed the following results:

TABLE 95. — AVERAGE PRODUCTION IN AMERICAN STONE TRADE.

Kind of stone.	Total number of operators.	Total value of annual product.	Average annual product per operator.
Granite.....	853	\$18,257,944	\$21,404
Slate.....	174	5,696,051	32,736
Sandstone.....	1211	10,601,171	8,754
Limestone.....	3137	30,441,801	9,704
Marble.....	75	5,044,182	67,256

It requires only cursory examination of these figures to prove that the average quarry operator, especially in the sandstone and limestone industries, is not a very important business interest. In view of the fact that this condition is likely to change, and that the larger companies to come must base their capitalization on the experience of the present, it will be profitable to consider these matters in somewhat more detail.

Average Costs and Profits. — The latest detailed figures relative to the American stone industry in 1902 are to be found in a report of the Twelfth Census. The figures in the following table are copied from that volume.

TABLE 96. — DATA RELATIVE TO THE AMERICAN STONE INDUSTRY IN 1902.

	Granite.	Slate.	Sandstone.	Limestone.	Marble.
Number of firms or corporations.....	853	174	1,211	3,137	75
quarries operated.....	906	199	1,304	3,246	83
Number of salaried officials.....	1,377	437	847	2,231	352
laborers.....	18,836	5,920	10,448	31,547	4,070
Total power employed, H.P.....	46,986	25,454	25,652	64,500	14,286
Total expense for salaries.....	\$1,227,885	\$334,879	\$713,579	\$1,843,747	\$341,021
wages.....	11,072,996	3,177,459	6,153,060	14,750,638	2,212,640
quarry rent, royalties, etc.....	194,892	269,267	195,968	422,693	65,385
office rent, taxes, etc.....	615,314	176,878	682,812	1,017,388	317,492
supplies and materials.....	2,493,065	680,361	1,298,190	5,403,912	825,822
Total costs.....	\$15,604,152	\$4,638,844	\$9,043,609	\$23,438,378	\$3,762,360
Total value of product.....	18,257,944	5,696,051	10,601,171	30,441,801	5,044,182

The Census Report figures, though interesting in themselves, can readily be treated so as to give more valuable data on costs. Unfortunately the report gives no hint as to the *quantity* of stone produced during the year, so that the costs per cubic foot cannot be deduced. But the elements that make up the total cost in each industry can be determined, as well as the percentage of profit. All these factors can be expressed in percentages of the total cost.

TABLE 97.—ELEMENTS OF COST IN STONE QUARRYING IN PERCENTAGE OF TOTAL COST.

	Granite.	Slate.	Sand-stone.	Lime-stone.	Marble.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Salaries.....	7.88	7.22	7.89	7.86	9.07
Wages.....	70.97	68.49	68.04	62.94	58.81
Quarry rent, royalties, etc.....	1.24	5.81	2.17	1.80	1.74
Office rent, taxes, etc.....	3.94	3.81	7.55	4.34	8.43
Supplies and materials.....	15.97	14.67	14.35	23.06	21.95
Total costs.....	100.00	100.00	100.00	100.00	100.00
Value of product.....	117.01	122.8	117.2	129.87	134.1

The Financing of the Future.— From the data given in previous paragraphs it can be readily understood that the stone trade of the present day is on a very different basis from most of the other large industries. For the most part, it is handled by small operators, whether individuals, firms, or corporations. In many cases, particularly in the sandstone and limestone trades, the quarries are operated only at intervals, and are not the most important business interests of their owners. It is, in the writer's opinion, highly improbable that this condition will last much longer, for in many cases there are opportunities for the development of the business on a larger scale.

If the stone trade of the future is to be a more highly concentrated industry, it will require financing on a different basis than is now employed. A company operating a number of quarries, in different localities and on different classes of stone, must put all of its affairs on a permanent and definite basis. And it is this type of company, capable of taking contracts for any type of stone at any delivery point, that seems to offer the only possibility for large profits in the stone industry.

Characteristics of Industrial Bonds.— Among the few quarry

companies which have offered their securities during the past few years, there is seen the same tendency toward financing by means of bond issues that has become so serious a feature in other industries.

As distinguished from railroad bonds, industrial bonds are inherently subject to one point of danger.

A railroad line, even if temporarily unprofitable, is rarely entirely abandoned, for the growth of traffic with the growth of the country will gradually transform it into a profitable enterprise. In addition the natural increase in the value of the real estate which it must own, and particularly in the value of its terminals, aids in placing material assets in back of its bonds, irrespective of the earning power of the line itself. This condition is characteristic of a growing country, and can be expected to persist for some time in the United States. When it finally ceases, railroad securities will lose one great element of their strength as compared with industrials. But until that time comes this condition must be reckoned with.

An industrial bond, on the other hand, must always face the danger that the original project was inherently unsound in plan. Men embark in new industries, or in old industries at new locations, with the expectations that a marketable product can be made at a given point, that it can secure a sufficiently large market, and that the prices realized will be above the cost of manufacture and delivery. If all of these expectations are realized the operation will be profitable. But if any one of the three elements turns out to have been estimated erroneously, the enterprise will necessarily be unprofitable. This in turn will finally mean default on the bond interest, for which the only remedy is foreclosure — and in the case of an unsuccessful industrial enterprise foreclosure offers little hope for the bondholders. Unless it can be determined that the failure is due, not to inherent unsoundness of the project, but to mismanagement, there is, of course, no inducement for anyone to reorganize the company and to put the plant into operation again. The scrapping value of an inactive and unsuccessful mill is small, and there is rarely sufficient real estate to aid materially in paying off the bonds.

Raw Materials as a Basis for Bond Issues. — The effect of these conditions must be considered when an attempt is made to

place a value on bonds issued by a quarry company. Especial care must be taken when the bond issue is so large that some or all of it is based, not on tangible property, but on an assumed value for the stone properties held. Each case must, of course, be considered separately, but the writer believes that the following rules will be found almost universally applicable.

1. Under ordinary competitive conditions, the raw materials should not be credited with any value whatever in determining the security back of a proposed bond issue on a new quarry enterprise.

2. If the stone to be quarried is of a peculiarly desirable quality, and if the supply is so closely controlled as to possess a distinct and measurable monopoly value, this can be taken into the account.

3. If the operation, though the supply of stone is not entirely controlled, possesses differential freight rates to an important market over its nearest possible competitor, the increased profits arising from this source can fairly be considered as an element in valuation, and some portion of these excess profits can safely be capitalized in the form of bonds.

Stock Issues against Quarry Projects.—In the preceding sections it has been pointed out that bonds issued against new quarry projects are necessarily open to criticism, and are often, if not usually, of doubtful security.

With regard to stock issues the case is very different. There is no absolute necessity that bonds be issued at all, but there is the practical certainty that any large enterprise will be put in corporate form, and this implies the issue of at least one class of stock. There is, therefore, no question as to the necessity or propriety of a stock issue, the only problem being the proper size of such issue. The question here concerns the practice which public-spirited Congressmen from agricultural districts hold up to public execration as *stock watering*.

From the rigidly conservative point of view, stock watering is the issue of stock in such quantity that the total par value of the outstanding securities exceeds the amount of cash actually invested in the enterprise. If this definition were commonly accepted, it might truthfully be said that no business corporation, in any country or at any time, ever had absolutely unwatered stock.

The banker or business man interested in industrial enterprises, however, would modify this definition materially. To him, watered stock is stock issued in excess of the capitalized value of the average annual net profits of the enterprise. In the case of an established industrial enterprise, this capital value might be estimated by capitalizing the actual average net earnings, over a term of years, after allowing for depreciation and other proper charges, on a 7 per cent basis. In the case of an entirely new enterprise, since the prospective profits are certain to be estimated too high, the average probable earnings could only be capitalized on a much higher interest basis, say, at a 10 or 15 per cent rate.

CHAPTER XII.

LABORATORY TESTING OF STONE.

Trend of Testing Methods. — Though cement and stone are closely related structural materials, the study and testing of their properties have taken curiously divergent courses.

The subject of cement testing has for many years been of great interest to both engineers and cement manufacturers, and much attention has been paid to devising methods which would best bring out the structural value of the material. Through the efforts of powerful engineering and trade societies, both general tests and methods of manipulation have become fairly well standardized, and it is now possible to compare, within certain limits, results obtained by different workers and in different laboratories. The German Association of Portland Cement Manufacturers has done much in this direction, while in the United States the American Society of Civil Engineers has taken the lead in the standardization of physical tests of cement, and the Society of Chemical Industry has been engaged in securing uniformity in the methods of chemical analysis. The testing of cement, as compared with that of building stone, has, of course, the advantage that information gained by tests can be applied to the methods of manufacture so as to avoid, in future, defects which may have been detected.

The testing of structural stone has, in the meantime, taken an entirely different course, and with less satisfactory results. Though earlier contributions to the study of the subject had been made, the work of Gen. Q. A. Gillmore thirty years ago may be regarded as the foundation on which the modern study of building stone testing has been based. The accuracy of certain of Gillmore's conclusions may be questioned, but the real value of his work cannot be minimized. Physical methods of testing building stone have advanced but slightly since his day.

Since the time of Gillmore's work, however, another phase of the subject has been studied. The principal recent investiga-

tions have been made, not by engineers, but by geologists; and these have been concerned with the durability, rather than with the strength of the material examined. This fact has exercised a very appreciable influence on the course which the study has taken. Any present-day report on building stones, whether it be a private report on individual quarries or a public report issued by Federal or State geological surveys, will be found to show the influence of the classic work of Hawes, Merrill, and Julien, as embodied in the "Report on Building Stones," which forms Vol. 10 of the Tenth Census Reports.

The result of the division of the subject between geologists and engineers has been that little attempt to secure uniformity of methods has been made by any of the engineering societies which alone are strong enough to carry out such an attempt. This unsatisfactory condition, which prevents comparison of the results obtained in different laboratories, is due in large part to the complexity of the subject, and in so far can be obviated only by further work. It is due in part, however, to the conditions under which previous investigations have been carried on, and to better these united effort is essential.

It would appear desirable that this subject be taken up by one or more of the American engineering societies, which alone possess sufficient influence to make any proposed series of tests the standard. In one way, indeed, it will be easier to secure uniformity in this branch of investigation, for testing machines capable of handling a stone cube are much fewer in number than are the smaller machines used for testing cements.

Data Required from Tests. — The points which an engineer or architect desires to know concerning any building stone are two in number:

- (1) Is the stone strong enough for the use to which it is to be put?
- (2) Will the stone retain its strength, structure, and color after exposure for a long series of years to the natural and artificial agencies which may be expected to attack it?

The two prime requisites of a building stone are, therefore, *strength* and *durability*; and most of the different tests which will be discussed in the present chapter have been devised merely to determine one of these two points, either directly or indirectly. This fact is sometimes lost sight of by the experimenter who, in

his zeal for distinction, devises tests which may be of interest in themselves but which throw no light on the questions of real importance.

Classes of Tests Applied. — As a matter of convenience, it seems advisable to group the various possible laboratory tests according to the *kind* of information which they will give regarding the specimen under test. This has accordingly been done in the following scheme.

I. Tests to determine composition and structure	{ Chemical analysis Microscopic examination
II. Tests to determine density	{ Specific gravity Weight Porosity
III. Tests to determine durability	{ Absorption Freezing Sulphate of soda Resistance to acids Heat
IV. Tests to determine strength	{ Compression Transverse Shear Elasticity Fatigue Hardness Abrasion Impact

I. TESTS TO DETERMINE COMPOSITION AND STRUCTURE.

Chemical Tests. — In regard to uniformity in analytical methods marked progress has been made during the past few years. Dr. W. F. Hillebrand has described* in great detail the methods of rock analysis followed in the laboratory of the United States Geological Survey, and it seems probable that future progress in the standardization of such methods will follow closely along the lines of his paper. The analysis of materials for the manufacture of Portland cement, a subject which necessitates discussion of analyses of limestone, has been reported† upon by a committee of the Society of Chemical Industry. If followed

* W. F. Hillebrand. Some principles and methods of rock analysis. Bull. 176, U. S. Geol. Sur.

† Report of the subcommittee on uniformity in analysis of materials for the Portland cement industry. Jour. Soc. of Chem. Ind., vol. 21, pp. 12-30.

by chemists engaged in industrial work, the methods advocated in the two papers noted will result in greater accuracy in determining the chemical composition of rocks, as well as greater uniformity in the statement of results.

→ The practical value of a chemical analysis depends largely on the type of rock in question. In the case of a granite, trap, or other crystalline igneous rock, an analysis is of itself of little service, though it may do some good if taken in connection with a careful microscopical investigation. With sandstones, analyses are somewhat more useful, in determining the character of the cementing material, though even here a microscopical investigation will probably be more serviceable. The value of a chemical analysis is greater in the case of limestones and slates, particularly the latter.

Microscopic Examination.—The examination, under the microscope, of thin sections of a stone serves to determine the characters and condition of the component minerals, the shape and method of aggregation of the individual grains; and, in the case of sedimentary rocks, the character of the cementing material. Microscopic examination, therefore, is perhaps the most valuable single test; but it is the one which can least readily be applied by the quarryman or engineer, as instruments and training are rarely obtainable.

II. TESTS TO DETERMINE DENSITY.

Of the various properties of stone that may be selected for testing, three are so intimately related that they must be considered together under the head of tests to determine density. The three properties in question are:

- (1) Specific gravity.
- (2) Weight per cubic foot.
- (3) Porosity.

Of these, the first and second are readily determinable by direct experiment. The third cannot readily or accurately be determined by experiment, but can be ascertained by calculation when the weight and specific gravity are known.

Interrelation of These Properties.—The specific gravity of any mass of material is the ratio between its density and that of an equal volume of water. There is, therefore, a very simple relation between the specific gravity of any nonporous body

and its weight per cubic foot, and the two are convertible according to the following formulas, assuming that a cubic foot of water will weigh 62.4 pounds.

(1) Specific gravity \times 62.4 = weight in pounds per cubic foot.

(2) $\frac{\text{Weight in pounds per cubic foot}}{62.4} = \text{specific gravity.}$

If we were dealing with a thoroughly homogeneous and non-porous material, such as rolled steel or coined gold, the above statements would cover the whole case. But in dealing with stone, which is rarely homogeneous and usually very porous, the matter becomes more difficult, and any apparently simple, direct statement regarding it is apt to be misleading.

The difficulty arises from the fact that a stone is made up of a number of solid nonabsorbent mineral particles, separated by pore spaces of greater or lesser size and amount. We might attempt to determine the specific gravity of the stone by simply weighing a fragment in air and then in water, using the familiar formula:

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Loss of weight in water}}.$$

But the value thus obtained would not be the true specific gravity of the stone. It would always be lower than the true specific gravity, because of the pore spaces in the rock. This fact is often stated in discussions of testing methods, and various devices have been employed to overcome the difficulty. ~~In the opinion of the writer these attempts have been wrongly directed, and have tended to lessen the accuracy of the results rather than increase it.~~

The *true specific gravity* of any stone is equal to the specific gravity of its solid particles. It can only be determined, therefore, by grinding the stone to powder, and finding the specific gravity of this powder. Any other method of ascertaining it will give erroneous results, the amount of the error being proportional to the porosity of the original rock.

The *weight per cubic foot* of the stone can best be obtained by direct weighing of a carefully measured cube or slab. The accuracy of this direct method depends on the precision of the measurements and weighing, and on the smoothness of the faces

of the cube. A polished specimen, for example, should give very accurate results.

The *porosity* of the stone can be deduced if the true specific gravity and weight per cubic foot are known. The formulas for converting these three factors are as follows:

g = true specific gravity of powder.

w = apparent weight per cubic foot by direct weighing.

p = percentage of pore space.

$$(1) \quad w = 62.4 g \times \frac{100 - p}{100} \quad \text{or} \quad w = \frac{6240 g - 62.4 gp}{100}.$$

$$(2) \quad p = 100 - \frac{100 w}{62.4 g}.$$

$$(3) \quad g = \frac{100 w}{6240 - 62.4 p}.$$

These formulas are of use, of course, only when the *true specific gravity* and the *weight per cubic foot* of the stone have been correctly determined. When the so-called "specific gravity" and "weight per cubic foot" have been determined by the inaccurate methods in common use the formulas cannot be applied.

Methods of Determining Weight per Cubic Foot. — The weight per cubic foot of a stone, as that term is here used, is the actual weight of a cubic foot of the dry stone, without allowance for pore spaces.

Two methods may be employed in making this determination. The first of these, though apparently the cruder, is in reality subject to less error.

(1) **Direct Weighing.** — A cube or slab of the stone is carefully measured, and its volume calculated. It is then weighed with equal care. The weight per cubic foot is then, simply, weight in pounds per cubic foot = weight of specimen in pounds \times

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volume of specimen in cubic inches. The specimen, before weighing, should have been dried for several hours at a temperature of about 110° C. in order to remove water. As errors in either measuring or weighing decrease as the size of the specimen increases, it should be as large as possible. With polished, well-squared specimens the results obtained by this method are very accurate. Their accuracy decreases, of course, as the faces

of the cube or slab are rougher or more irregular; but the cubes employed for compression tests will give very satisfactory results.

(2) **Weighing in Water.** — A method which some testing laboratories use to determine what they erroneously call the “specific gravity” of stone, is in reality a very fair method for obtaining its weight per cubic foot.

The specimen is dried and weighed in air. It is then suspended in water and weighed as quickly as possible, so as to avoid much absorption. If w equals weight in air, and w^1 , weight in water, then:

$$\text{Weight in pounds per cubic foot} = \frac{w}{w - w^1} \times 62.4.$$

Porosity. — The percentage of porosity of a stone is the ratio between the volume of pore spaces in any specimen and the total apparent volume of the specimen. There is no simple method of determining this by direct experiment, but on a preceding page it has been pointed out that the porosity can be calculated readily if the true specific gravity and the apparent weight per cubic foot have been determined. The formula to be used for this purpose is

$$p = 100 - \frac{100 w}{62.4 g}$$

in which p = percentage of pore space.

w = apparent weight in pounds per cubic foot.

g = true specific gravity.

The value thus obtained is of interest simply as fixing a maximum for the amount of water that can be absorbed by the stone under the most favorable circumstances possible. Actually, as below noted, the absorption rarely approaches this theoretical maximum.

Value of Density Tests. — (1) When stone is to be used for certain purposes, a high weight per cubic foot is *per se* an advantage. This is particularly the case with regard to stone to be used under water, as in dams, breakwaters, and shore protection works. For such purposes a trap, weighing perhaps 180 pounds per cubic foot, is a far more satisfactory material than a sandstone weighing only 140 pounds. The real ratio

between the value of these two stones would not be simply that of their weights, as 180 : 140, but a much higher ratio. As Johnson has pointed out, the effective weight of a stone in under-water construction is its weight minus that of an equal quantity of water. In the example just cited, therefore, the real ratio of effectiveness between the two rocks would not be simply

$\frac{180}{140}$ or 9 : 7, but

$$\frac{180 - 62.4}{140 - 62.4} = \frac{117.6}{77.6} \text{ or almost } 11 : 7.$$

Obviously there is a distinct advantage to be gained by using stone of high specific gravity for such purposes.

(2) Aside from the case above mentioned, where high specific gravity is of itself desirable, it is always desirable because of the other physical properties which it indicates. It may be accepted as axiomatic that *in any particular group of stones, the one showing the highest weight per cubic foot is almost certainly the strongest and least absorbent.* A limestone weighing 160 pounds per cubic foot is, therefore, other things being equal, to be preferred to one weighing only 140 pounds. The same is true with regard to sandstones. Granites and traps, however, show such a small percentage of absorption that the relation between weight and absorption becomes of little practical importance.

III. TESTS TO DETERMINE DURABILITY.

Expansion. — It has long been recognized that much of the lack of durability of building stone is due to the effects of changes of temperature. These operate to disintegrate the stone because, except in the case of an entirely homogeneous material, the various component minerals will have different ratios of expansion on heating, as in a granite, while in sandstones the cementing material and the enclosed grains or fragments may expand unequally.

The tendency of a stone to exfoliate or disintegrate under changes of temperature can obviously be tested directly, and uniformity in the method of applying the test may be obtained without difficulty.

Absorption. — The mineral particles of which a stone is composed are themselves practically nonabsorbent, but a certain amount of space always exists between these particles. This *percentage of pore space* can be determined from formula 2 on page 200. Its principal interest lies in the fact that it fixes a maximum limit for the amount of water that the stone *can* absorb. A stone containing 5 per cent of pore spaces can obviously never absorb more water than would fill this 5 per cent of unoccupied space. In reality, under ordinary conditions, it would never absorb nearly as much as this theoretical maximum. Direct absorption tests can of course be readily carried out; and would be of value if different experimenters would accept some definite standards of practice in the matter.

Frost Tests. — Changes of temperature, as indicated above, may of themselves cause serious injury to a stone; but when taken in connection with the action of water contained in the pores of the stone, the effect is greatly augmented. The tests applied for expansion are mainly to determine the effect of alternate heating and cooling, and particularly of high heating and rapid cooling. The tests for porosity or absorption, on the other hand, are carried out with a view to determining the probable resistance of the stone to the action of frost. Other things being equal, it is obvious that the stone which absorbs the greatest quantity of water per cubic inch in a given time will be the stone that is subject to the greatest injury at low temperature, owing to the freezing of the water contained in it. It is of course desirable to check up this mode of reasoning by carrying out actual freezing tests; and several valuable series of such tests are on record.

The action of frost is frequently simulated by using in the absorption test, instead of pure water, a saturated solution of some salt, of which expansion, on solidifying, would tend to crack or disintegrate the stone. Tests of this type have, however, fallen largely into disuse. They will be discussed briefly after actual freezing tests have been considered.

In 1890 Gerber * tested a small series of western building stones, the specimens being subjected to alternate thawing and freezing by immersing them in water during the day, and at night placing them in cold storage rooms kept at an average temperature of

* Trans. Am. Soc., Vol. 33, p. 253.

0° to 4° F. This was done for about twelve days, and resulted in the following losses of weight:

TABLE 98.—EFFECT OF FREEZING TESTS. (GERBER.)

Kind of stone.	Location.	Loss of weight in per cent.
Limestone.....	Bedford, Ind.....	0.097
“.....	Bedford, Ind.....	0.103
“.....	Stone City, Iowa.....	0.134
“.....	Stone City, Iowa.....	0.053
“.....	Mankato, Minn.....	0.113
“.....	Mankato, Minn.....	0.106
“.....	Winona, Minn.....	0.049
“.....	Winona, Minn.....	0.043
“.....	Hannibal, Mo.....	0.154
Sandstone.....	Ashland, Wis.....	0.068
“.....	Ashland, Wis.....	0.088

Beare * subjected a small series of British building stones to actual freezing tests. The cubes were soaked in water all day, and then at night placed outside, being thus subjected to temperatures of from 20° to 32° F. In the morning the specimens were brought inside and thawed by gentle warming. This process was repeated ten or twelve times, and then the cubes were exposed to the atmosphere and rains for two or three weeks in thawing weather. On weighing and testing it was found that (1) granite cubes showed no perceptible loss of weight; (2) some limestone and sandstone cubes showed losses, never exceeding one-fifth of 1 per cent; (3) none of the cubes showed any loss of *strength* as compared with unfrozen cubes. Taking into consideration the fact that most of the limestones tested were porous, loose-grained volites, and that the group of sandstones also included some very porous specimens, the small loss of weight would seem to prove that this method of testing could hardly be regarded as satisfactory.

Buckley's tests on Wisconsin stones gave the following results:

* Proc. Institute Civil Engineers, vol. 107, pp. 350, 351 (1892).

TABLE 99. — EFFECT OF FREEZING TESTS. (BUCKLEY.)

Kind of stone.	Quarry.	Location.	Loss of weight by freezing. Per cent.	Compressive strength, pounds per square inch.	
				Before freezing.	After freezing.
Granite	Amberg Granite Co..	Athelstane.....	.025	19,988	10,619
	Berlin Granite Co....	Berlin.....	.000	24,800	36,009
	Nelson Granite Co....	Berlin.....	.03	45,841	32,766
	French Granite Co....	High Bridge.....	.006	24,229	16,019
	Granite Heights Co..	Granite Heights	.025	22,507	20,306
	Jenks' quarry.....	Irma.....	.035	18,023	15,764
	Leuthold quarry.....	Granite City....	.02	25,000	14,886
	Milwaukee Mon. Co..	Berlin.....	.015	34,640	31,844
	Montello Granite Co..	Montello.....	.01	38,244	35,045
	New Hill o' Fair.....	Granite Heights	.05	27,262	19,368
	Pike River Granite Co.....	Amberg.....	.015	23,062	20,442
Limestone	Bauer's quarry.....	Knowles.....	.16	30,680	17,005
	Bridgeport Stone Co.	Bridgeport.....	.00	8,098	7,527
	Gillen Stone Co.....	Duck Creek....	.14	24,522	28,392
	Laurie Stone Co.....	Sturgeon Bay	.013	35,970	20,777
	Lee Bros. quarry.....	Genesee.....	.00	32,992	28,133
	Marblehead Stone Co.	Marblehead....	.00	41,620	27,366
	Menominee Falls Co.	Lannon.....	.00	32,710	13,986
	Giesen quarry.....	Fountain City..	.035	8,799	9,462
	Story quarry.....	Wauwatosa....	.012	18,477	25,779
	Voree quarry.....	Burlington....	.045	12,827	7,554
	Washington Stone Co.	Sturgeon Bay...	.08	30,745	14,943
Sandstone	Argyle Brownstone Co.....	Argyle.....	.435	4,173	2,220
	Ashland Brownstone Co.....	Presque Isle...	.175	5,495	5,930
	Babcock & Smith....	Houghton.....	.140	5,421	3,714
	Bass Island B. Co....	Bass Island.....	.115	4,718	4,808
	Duluth Brownstone Co.....	Fond du Lac....	.200	5,991	6,903
	Dunnville quarry....	Dunnville.....	.195	2,722	3,464
	Grover quarry.....	La Valle.....	.026	12,405	6,141
	Pike quarry.....	Bayfield.....	.13	4,040	2,958
	Port Wing quarry....	Port Wing.....	.133	5,329	4,399
	Prentice Brownstone Co.....	Houghton.....	.00	4,319	3,993

The Brard Test with Sodium Sulphate. — In order to obtain any very striking results, actual freezing tests have to be extended over a long period of time. To avoid this inconven-

ience, it was early suggested that the effect of frost might be simulated by immersing the specimen in a saturated solution of certain salts, and then allowing the absorbed salts to crystallize out of the stone. The salt most commonly used for this purpose is sulphate of soda, suggested first by Brard, whose name is therefore often attached to the test.

The test as carried out by Luquer was as follows:

A saturated cold solution of sulphate of soda was prepared. "The specimens, which had been carefully prepared, brushed, dried, and weighed, were boiled in the sulphate of soda for half an hour, in order to get complete saturation. At the end of the half hour it was noticed in every case that the solution was slightly alkaline, though at the start it had been neutral. In order to prevent any continued chemical action the beakers were emptied, the specimens rapidly washed with water, and the beakers immediately refilled with the neutral sulphate solution. After soaking for several hours, the specimens were hung up by threads, and left for twelve hours (during the night) in a dark room. In the morning all the specimens were covered with an efflorescence of the white sulphate of soda crystals; they were then allowed to soak in the solution during the day, and again hung up at night. Efflorescing for about twelve hours and soaking for about the same time constituted a period. The experiments lasted for eight periods. . . . During the tests the solution was renewed from time to time, and appeared to remain neutral. The temperature of the room varied from 60° to 70° F. (18° to 21° C.). Those specimens most affected began to show the disintegrating action of the solution very early in the course of the experiments. At the end of the ten (8 ?) days the specimens were sprayed with the stream from a wash bottle to remove any adhering particles, washed in water to remove the sulphate of soda, carefully dried in an air bath at about 120° C. and weighed again."

These tests were carried out in order to determine whether or not the sulphate of soda test gave results directly comparable with those obtained by actual freezing, a duplicate series of specimens being tested at the same time in the latter manner. The results of the two series of tests are presented in the following table, and it will be seen that the correspondence is far from satisfactory.

It may also be noted here that Gerber* carried out similar comparative tests, and that his results were equally unsatisfactory.

TABLE 100. — RELATION OF FREEZING AND SODIUM SULPHATE TESTS. (LUQUER.)

Kind of rock.	From	Loss of weight. Per cent.		Ratio of re- sults. Soda freezing
		Sul- phate of soda.	Freez- ing.	
Granite:				
Coarse-grained.....	Gallager's, Me.....	0.1551	0.0138	.....
Medium-grained.....	Jonesborough, Me....	0.0655	0.0176	.....
Fine-grained.....	Hallowell, Me.....	0.0516	*	.....
Fine-grained gneiss.....	Bedford, N. Y.....	0.0633	*	.....
	Keeseville, N. Y....	0.0384	†	.....
Marble:				
Coarsely-crystalline; magnesian	Pleasantville, N. Y..	0.1078	0.0310	.....
Medium-grained; magnesian...	Tuckahoe, N. Y.....	0.1701	0.0230	.....
Fine-grained; nonmagnesian....	?	0.2599	0.0207	.....
Sandstone:				
Fine-grained.....	Belleville, N. Y.....	0.4765	0.1063	.....
Coarser-grained.....	"	1.4518	0.1421	.....
Badly-decomposed.....	?	4.8212	0.6874	.....
Pressed brick.....	.....	0.2486	0.0686	.....

* About same as Jonesborough stone.

† Less than Jonesborough stone.

The defect of the Brard test becomes apparent when the above tests, or any other long comparative series, are examined carefully. The sulphate of soda method does give measurable results in short time. But its results are different from those of actual freezing tests not only in intensity but in kind. Chemical action is introduced which attacks the specimen in a way very different from that of frost, and the result is that the two tests are in no way comparable. Inasmuch as the only excuse for making the Brard test is the idea that its effects closely simulated those produced by frost, it is evident that it has failed in its mission, and that it requires no further consideration. It may be added that in these days of cold-storage warehouses it is not such a difficult matter to carry out actual freezing tests at any time of the year.

Resistance to Acids. — Structural stone, particularly when employed in manufacturing cities, may be subjected to attack by various acids present in the atmosphere. Carbonic acid is

* Trans. Amer. Soc. C. E., vol. 33, p. 253.

always present in air, though normally only in small percentages, while nitric, hydrochloric, sulphuric, and sulphurous acids occur in certain regions.

Though these acids are present in very small amounts, their effect on stone, when exerted through a long series of years, may be noticeably injurious, and accordingly various tests have been suggested to determine the amount of this effect on various kinds of stone.

In testing the influence of carbon dioxide, Wilber* used samples weighing about 50 grams. These were dried at 212° F. and weighed; then placed on a perforated shelf under a large bell jar. "The bell jar was placed in a shallow pan, and enough water poured into the pan to make a water seal for the bell jar. Inlet and exit pipes were introduced into it and a stream of washed carbonic acid passed into the jar until all air was expelled. The openings were then closed and the contents allowed to stand three days at a temperature of about 70° F. Carbonic acid gas was again passed in, and this operation was repeated, at intervals, during the fifty-two days of the continuance of the test. The samples were then removed and soaked for four days in distilled water, and were afterwards dried in an air bath, at a temperature of 212° F., to constant weight." The percentage of weight lost during the operation was then calculated, with the results shown in Table 101.

In the course of the New York series of tests already noted, Wilber also experimented † on the effects of dilute sulphuric acid. "Small cubes, three-fourths of an inch on a side, were used for this test. The samples were dried in a water bath at 212° F. to a constant weight. They were then placed upon a perforated support and immersed in dilute sulphuric acid. The acid solution contained one per cent of sulphuric acid, H_2SO_4 , and the volume used at once was two gallons. After an immersion of forty hours the acid was drawn off and replaced by a fresh supply. This remained upon the samples for twenty-four hours, when it was run off and a third fresh portion added, which was allowed to remain eight hours. It was then drawn off and a gentle stream of clear water passed through the vessel for some time, until the samples were entirely cleansed from the effects of the

* Bulletin 10, N. Y. State Museum, p. 357 (1890).

† Ibid, p. 358 (1890).

TABLE 101.—TESTS WITH ACIDS. (WILDER.) (*Continued.*)

Stone.	Locality.	CO ₂ .	S ₂ .	H ₂ SO ₄ .
Sandstone	East Longmeadow, Mass.....	0.046	0.055	0.12
	“ “ “.....	0.040	.....	.....
	“ “ “.....	0.081	0.051	0.17
	“ “ “.....	0.086	.....	.....
	“ “ “.....	0.076	.....	.....
	“ “ “.....	0.060	.....	.....
	“ “ “.....	0.074	0.146	0.11
	“ “ “.....	0.053	0.161	.....
	“ “ “.....	0.068	.....	.....
	Portland, Conn.....	0.074	0.059	0.55
	“ “ “.....	0.080	0.086	.....
	“ “ “.....	0.078	0.003	0.22
	“ “ “.....	0.090	.....	.....
	Belleville, N. J.....	0.031	0.040	1.01
	Berea, Ohio.....	0.066	0.170	0.45
	Lake Superior, Mich.....	0.005	0.100	0.36
Slate	Nova Scotia.....	0.025	0.020	0.20
	Bristow, Va.....	0.079	0.180	0.11
	“ “.....	0.104	0.100	.....
	Middle Granville, Washington Co., N. Y.	0.004	0.070	0.07

Resistance to Fire.—The most complete series of tests of the fire resistance of building stones are those by McCourt, from whose report the following extracts are quoted:

The samples from each locality were cut into three-inch cubes. Most investigators, who have studied the refractoriness of building stones, have selected one or two-inch cubes; but these sizes do not give as accurate results as the larger ones, for the reason that a small piece becomes easily heated throughout the mass and consequently upon neither heating nor cooling are differential stresses between the interior or exterior likely to be set up, as would be the case if larger cubes are selected. In actual fact in the burning of a building the stone does not become thoroughly heated; the heat penetrates probably but a slight distance into the mass, while the interior may remain comparatively cold. The heating and cooling of this outer shell causes strains which do not obtain in a stone which has been heated throughout its entire body. One, two and three-inch cubes of the same kind of stone have been tested in the laboratory, and while the smaller cubes stood fire very well, the larger ones were more affected and in some cases went to pieces. It was to avoid this error and to approach more closely the existing conditions in a conflagration that the three-inch samples have been employed in the present series of tests.

As far as the number of cubes would admit six tests were made on the stone from each locality, four furnace and two flame tests. For the first set of experiments a Seger gas furnace was used, thus allowing the cube to be gradually and evenly heated. An opening was cut in the cover of the furnace large enough to admit the three-inch cube of stone, to which a wire had been attached to facilitate its handling.

One sample was heated at a time. The heat was applied gradually for half an hour until a temperature of 550°C . was reached, which was maintained for half an hour. The temperature was measured with a thermoelectric pyrometer. The cube was then taken out and allowed to cool in the air. A second sample was heated, as before, to 550°C ., and this was suddenly cooled by a strong stream of water. The third and fourth cubes were heated to 850°C . kept at that temperature for half an hour and cooled slowly and suddenly as in the 550°C . tests.

In order to approach more nearly the conflagration conditions samples were subjected to two flame tests. In the first case the cube was so placed as to be enveloped on three sides by a steady but not strong gas blast. The flame was allowed to play on the cube for 10 minutes, then the samples were allowed to cool for five minutes after which time the flame was again applied for 10 minutes and the cube was again allowed to cool. To determine the combined action of heat and water a second cube was subjected, as before, to the flame for 10 minutes, then a strong stream of water was turned on to the sample, along with the flame, for five minutes. Then the water was turned off and the flame continued for another five minutes, after which, for five minutes more the flame and water together were allowed to act on the sample.

From the details of the tests above given some generalizations can be drawn which are of interest and of value. It is difficult, however, to group the different kinds of stone in any order, for they vary among themselves and also act differently under different conditions. A stone which under some conditions stands up very well, will disintegrate under other conditions. Thus, for example, the granite from Northville acted very badly on fast cooling after having been heated to 850°C ., yet, under the combined action of the flame and water, it was little damaged. Additional variations of this character are brought out by a close study of the tables of fire tests, all of which goes to show that, for one temperature, the order of resistance will differ from the order given for another temperature.

At 550°C . (1022°F .) most of the stones stood up very well. The temperature does not seem to have been high enough to cause much rupturing of the samples, either upon slow or fast cooling. The sandstones, limestones, marble, and gneiss were

slightly injured, while the granites seem to have suffered the least.

The temperature of a severe conflagration would probably be higher than 550° C., but there would be buildings outside of the direct action of the fire which might not be subjected to this degree of heat and in this zone the stones would suffer little injury. The sandstones might crack somewhat, but, as the cracking seems to be almost entirely along the bed, the stability of the structure would not be endangered, provided the stone had been properly set.

The gneiss would fail badly, especially if it were coarse-grained and much banded. The coarse-grained granites might suffer to some extent. These, though cracked to a less extent than the sandstones, would suffer more damage and possibly disintegrate if the heat were long continued because the irregular cracks, intensified by the crushing and shearing forces on the stone incident to its position in the structure, would tend to break it down. The limestones and marble would be little injured.

The temperature of 850° C. (1562° F.) represents fairly the probable degree of heat reached in a conflagration, though undoubtedly it exceeds that in some cases. At this temperature we find that the stones behave somewhat differently than at the lower temperature. All the cubes tested were injured to some degree, but among themselves they vary widely in the extent of the damage.

All the igneous stones and the gneiss at 850° C. suffered injury in varying degrees and in various ways. The coarse-grained granites were damaged the most by cracking very irregularly around the individual mineral constituents. Naturally, such cracking of the stone in a building might cause the walls to crumble. The cracking is due, possibly, to the coarseness of texture, and the differences in coefficient of expansion of the various mineral constituents. Some minerals expand more than others and the strains occasioned thereby will tend to rupture the stone more than if the mineral composition is simpler. This rupturing will be greater, too, if the rock be coarser in texture. For example, a granite containing much plagioclase would be more apt to break into pieces than one with little plagioclase for the reason that this mineral expands in one direction and contracts in another, and this would set up stresses of greater proportion than would be occasioned in a stone containing little of this mineral. The fine-grained samples showed a tendency to spall off at the corners. The gneiss was badly injured. In the gneisses the injury seems to be controlled by the same factors as in the granites, but there comes in here the added factor of banding. Those which are made up of many bands would be damaged more severely than those in which the banding is slight.

All the sandstones which were tested are fine grained and rather compact. All suffered some injury, though, in most cases, the cracking was along the lamination planes. In some cubes, however, transverse cracks were also developed.

The variety of samples was not great enough to warrant any conclusive evidence toward a determination of the controlling factors. It would seem, however, that the more compact and hard the stone is the better will it resist extreme heat. In a general way the greater the absorption, the greater the effect of the heat. A very porous sandstone will be reduced to sand and a stone in which the cement is largely limonite or clay will suffer more than one held together by silica or lime carbonate.

The limestones, up to the point where calcination begins (600° – 800° C.), were little injured, but above that point they failed badly, owing to the crumbling caused by the flaking of the quicklime. The purer the stone, the more will it crumble. The marble behaves similarly to the limestone, but, because of the coarseness of the texture, also cracks considerably. As has been mentioned before, both the limestones and marble on sudden cooling seem to flake off less than on slow cooling.

The flame tests cannot be considered as indicative of the probable effect of a conflagration upon the general body of the stone in a building, but rather as an indication of the effect upon projecting cornices, lintels, pillars, carving, and all thin edges of stonework. All the stones were damaged to some extent. The granites from Keeseville and Northville stood up very well; the limestones were, as a whole, comparatively little injured, while the marble was badly damaged. The tendency seems to be for the stone to split off in shells around the point where the greatest heat strikes the stone. The temperature of the flame probably did not exceed 700° C., so it is safe to say that in a conflagration all carved stone and thin edges would suffer. However, outside of the intense heat, the limestones would act best, while the other stones would be affected in the order: sandstone, granite, gneiss, and marble.

After having been heated to 850° C. most of the stones, as observed by Buckley,* emit a characteristic ring when struck with metal and when scratched emit a sound similar to that of a soft burned brick. It will be noted that in those stones in which iron is present in a ferrous condition the color was changed to a brownish tinge owing to the change of the iron to a ferric state. If the temperature does not exceed 550° C., all the stones will stand up very well, but at the temperature which is probable in a conflagration, in a general way, the finer-grained and more compact the stone and the simpler in mineralogic composition the better will it resist the effect of the extreme heat. The order,

* Mo. Bureau Geol. and Mines, Ser. 2 (1904), 2: 50.

then, of the refractoriness of the New York stones which were tested might be placed as sandstone, fine-grained granite, limestone, coarse-grained granite, gneiss, and marble.

IV. TESTS TO DETERMINE STRENGTH.

Crushing Strength. — It has often been pointed out that no stone which an engineer is likely to use will ever fail by crushing, for even in such massive masonry structures as the Washington Monument and the Brooklyn Bridge piers the compression per square inch at the base is much below that which even a relatively weak building stone will bear. It is pointed out, moreover, that though a small test piece of a given limestone may fail by crushing at, say, 12,000 pounds per square inch, every natural exposure of the rock proves to us that in larger masses it is practically uncrushable. In spite of these facts, the test most commonly carried out, when quality of a stone is in question, is that for crushing strength.

Even though this test be unnecessary, it could, if carried out uniformly, give us certain information of value, and be a means of comparing the strength of different stones. Unfortunately, however, there is at present little uniformity in the matter. The apparent "compressive strength per square inch," as shown by any given stone in the testing machine, is known to vary with the shape of the test piece, its size, and the character of the bearing surfaces; but sufficient experiments have not been carried out to determine the laws of these variations.

In the matter of size of test piece, Gillmore's earlier experiments seemed to prove that a large cube gave higher compressive resistance per square inch than a small cube, and he constructed a formula showing the variation in compressive strength in relation to size of cube. This formula will frequently be found quoted in engineering and geological treatises, though within a year of its announcement Gillmore had determined, from the results of a longer series of experiments, that the so-called law did not hold true.

Regarding the shape of test piece, it has been determined that a prism whose height is one and one-half times the width of its base will give far more accurate results than the cube. This determination has had little effect on testing practice, however, the cube being employed as heretofore.

TABLE 102.* — EFFECT OF BEARING MATERIALS ON STRENGTH OF SANDSTONE. (BEARE.)

Name of stone.	Average compressive strength.		Loss of strength due to lead, per cent.
	Plaster of Paris, pounds per square inch.	Lead sheet, pounds per square inch.	
Binnie.....	6,339	3,942	37.8
Hermant.....	6,115	3,942	35.5
White Hailes.....	10,382	4,637	55.3
Arbroath.....	8,682	4,995	42.5
Craigleith.....	13,408	6,361	52.6

* Proc. Institution Civil Engineers, vol. 107, p. 344.

TABLE 103. — EFFECT OF POSITION ON CRUSHING STRENGTH OF STONE.

Kind of rock.	Locality.	Tested by	Size of cube.	Ult. compr. strength, lbs. per sq. in.		Ratio, bed ÷ edge.
				Bed.	Edge.	
Syenite	French Creek, Pa.....	R. L. Humphrey...	In.			
	" " " " " "	" " " " " "	8	17,274	7,910	2.18
Gneiss, light color	Chester, Pa.....	" " " " " "	2	19,997	14,348	1.38
	" " " " " "	" " " " " "	8	9,505	6,426	1.48
Gneiss, dark color	Germantown, Pa.....	" " " " " "	2	6,097	5,446	1.12
	" " " " " "	" " " " " "	8	11,636	13,984	0.83
	Holmesburg, Pa.....	" " " " " "	2	19,891	15,555	1.28
	" " " " " "	Lathbury & Spackman.....	5½	21,684	19,527	1.11
Mica schist	Conshohocken, Pa. ...	R. L. Humphrey...	8	10,417	7,532	1.38
	" " " " " "	" " " " " "	2	20,038	15,680	1.28
Roofing slate	Brownville, Me.....	Mass. Inst. Tech....	1	29,270	16,750	1.75
Sandstone	Curwensville, Pa.....	R. L. Humphrey	8	7,513	4,463	1.68
	" " " " " "	" " " " " "	2	10,218	8,013	1.27
	Lumberville, Pa.....	" " " " " "	8	14,841	8,637	1.72
	Langford, Ky.....	Watertown Arsenal..	2	15,135	12,341	1.23
	Albion, N. Y.....	" " " " " "	2	27,703	22,923	1.29
	Berlin Hts., Ohio.....	Gillmore.....	3	14,250	12,000	1.19
Limestone	Bowling Green, Ky...	Watertown.....	5	6,998	6,387	1.10

TABLE 104. — EFFECT OF METHOD OF DRESSING CUBES.*

	Modulus of		
	Rupture.	Compression.	Elasticity.
Sawed specimens, average.....	2,338	12,675	4,889,480
Tool-dressed specimens, average.....	1,477	7,857	2,679,475
Ratio of strength, tool-dressed ÷ sawed...	63%	62%	55%

* 11th Ann. Rep. Indiana Dept. Geology, p. 39 (1881).

Transverse Strength.— Little attention is usually paid to testing the transverse strength of building stones, except in the case of stones intended for use as flagging, lintels, etc. This neglect is the more curious because building stone, in actual construction, often fails under transverse strain, as may be seen in the walls of many buildings. In theory, of course, a building should be so constructed as never to subject its wall material to anything but a direct compressive strain. In practice, however, the case is very different. Owing to bad masonry work, or more generally to the unequal settlement of foundations, transverse strains do frequently occur, and their effect is shown by vertical cracks in the poorer or weaker stones of the walls.

In determining transverse strength the formula used is:

$$R = \frac{3L}{2 \cdot BD^2} \cdot W,$$

in which formula

R = modulus of rupture in pounds per square inch.

W = concentrated load at center in pounds.

L = length between supports, in inches.

B = breadth in inches.

D = depth in inches.

Hardness.— The resistance of stone to mechanical wear is rarely of sufficient importance to justify testing, when the stone is used strictly as a building material. Flagging, steps, and sills are, however, subjected to considerable wear, and it is possible that some simple abrasion test might be of service. The only structural stone, however, that really fails, owing to ordinary mechanical wear, is serpentine, which is entirely too soft to be used in any unprotected situation.

LIST OF REFERENCES ON TESTS OF BUILDING STONE.

In addition to such general works as those of Gillmore, Merrill, Johnson and the Watertown Arsenal reports, the references in the following list may be found serviceable.

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PART II. CLAYS.

CHAPTER XIII.

CLAYS: GENERAL CLASSIFICATION.

Definitions of Clay, Shale, and Slate. — The term *clay* is applied to fine-grained unconsolidated natural materials which possess the property of plasticity when wet, while they lose this property and harden on being strongly heated. Clays are readily molded in all desirable shapes when wet; and this property is one factor in the usual commercial definition of a clay: though the typical kaolins are not plastic. Since the clays are, as described below, the finer débris resulting from the decay of many different kinds of rocks, they will naturally differ greatly among themselves as regards composition, properties, etc., and these differences prevent the formulation of a more precise definition.

Clays are rock material in an exceedingly fine state of subdivision, ultimately derived from the decay of older rocks, the finer particles resulting from this decay being carried off and deposited by streams along their channels, in lakes, or along parts of the sea coast or sea bottom as beds of clay. In chemical composition the clays are composed essentially of silica and alumina, though iron oxide is almost invariably present in more or less amount, while lime, magnesia, alkalies, and sulphur are of frequent occurrence, though usually only in small percentages.

The materials known respectively as *shales* and *slates* are of practically the same composition and ultimate origin, but differ in their degree of consolidation.

Shales are clays which have become hardened by pressure. The so-called "fire clays" of the coal measures are shales, as are many of the other "clays" of commerce. The *slates* include those clayey rocks which through pressure have gained the property of splitting readily into thin parallel leaves.

Origin of Clays; General Statement. — When rocks of any kind are exposed to atmospheric action, more or less rapid disintegration sets in. This is due partly to chemical and partly to physical causes. It is hastened, for example, by the dissolving out of any soluble minerals that may occur in the rock, by the expansion and contraction due to freezing, and by the action of the organic acids set free by decaying vegetable matter. The more soluble ingredients of the rock are usually removed in solution by surface or percolating waters, while the more insoluble portions are either left behind or are carried off mechanically by streams. These relatively insoluble materials, when sufficiently fine-grained, constitute the clays. When they are left as a deposit in the spot where the original rock disintegrated they are called *residual clays*, while if they have been removed from the site of the present rock they are termed transportation clays. If the materials are carried off mechanically by surface waters and finally deposited along river beds, in lakes, or in the sea they are termed *transported* or *sedimentary* clays. In a third class, of limited areal distribution but of considerable importance where they occur, are the *glacial* clays which owe their position to the great ice sheets which formerly covered most of the northern portion of the United States, the clays in question having been deposited under or in front of these glaciers. A class of still more limited extent and importance includes the *eolian* or wind-borne clays, the example usually quoted being the loëss clays, which are supposed by some geologists to have been transported and deposited by the winds.

So far as origin is concerned, clay deposits are therefore due to the coöperation of two sets of agencies — chemical and mechanical. With regard to the residual clays, chemical agencies have in some cases been the more important; but the transported or sedimentary clays are, in their present deposits, due almost entirely to purely mechanical causes.

Classification Based on Origin. — The facts which have been briefly stated above naturally lead toward a classification of clays based on the methods of origin and of deposition. A satisfactory working classification of this type is presented below in outline form; after which each of the groups named in this outline will be separately discussed in more detail.

A. Residual clays, resulting from the decay in place of

igneous rocks, of shales, or of clayey limestones. This group may be subdivided into three, according as the clay is derived.

1. From the decay of igneous rocks.
2. From the decay of shales or slates.
3. From the decay of more or less clayey limestone.

B. Transported clays, resulting from the *transportation* by water (or more rarely by ice or wind) of both the residual clays of Class A and of all sorts of finely-ground rock material, and the *deposition* of this material at favorable points more or less distant from its point of origin. The clays of this class may be subdivided according to their method of transportation, their point of deposition, or their present physical state. A sub-classification recognizing these three factors is as follows:

1. Water-borne clays; transportation effected by water.
 - (a) Marine clays, deposited in salt-water basins.
 1. Marine clays proper (i.e., soft clays).
 2. Shales.
 3. Slates.
 - (b) Stream clays, deposited along the courses of streams or rivers.
 - (c) Lake clays, deposited in lakes or ponds.
2. Ice-borne or glacial clays; transportation effected by glacial ice.
3. Wind-borne or eolian clays; transportation effected by the wind.

CHAPTER XIV.

RESIDUAL CLAYS.

Origin of Residual Clays. — The residual clays owe their origin to the decay or disintegration of some rock mass under the action of natural agencies, and to the consequent accumulation of the more insoluble or resistant portions as a residual material on the surface of the parent rock. The natural agents which effect this decay and disintegration may be either chemical or mechanical — usually both sets of forces are at work. The manner in which the decay and disintegration of the rock are produced will depend on the character of the agent and on the character of the rock. The methods of action and the effects produced are so different, on different types of rock, that it seems advisable to discuss the subject under three special headings, each of which will cover the formation of an important class of clay deposits. By far the majority of residual clays are derived from the decay of igneous rocks, of shales, or of clayey limestones — for the sandstones rarely yield clay deposits of any kind.

Residual from Decay of Igneous Rocks. — The igneous rocks usually contain a number of minerals, some of which are comparatively unaffected by weathering, while others yield with considerable rapidity. A granitic rock may be taken for example, composed of quartz, feldspar, mica, and probably a little hornblende. When a rock of this character is exposed at the surface, its quartz would be practically unaffected by the ordinary weathering agents; its feldspar would decay with comparative rapidity, while its mica and hornblende would also alter, though less strikingly than the feldspar. Extremes of cold and heat would tend to disintegrate the rock physically, and so make its minerals more open to attack from percolating waters carrying dissolved acids.

The decay of feldspars undoubtedly gives rise to certain clay deposits of interesting type, and though the importance of this

fact has been greatly exaggerated in clay literature, the subject is worth some consideration here.

The feldspars are essentially silicates of alumina and potash, soda or lime. The composition of the different feldspar species is discussed in some detail on page 25, to which reference should be made for further data on the subject. In the present case it will be sufficient to take up the most familiar variety of feldspar — orthoclase — and to trace the changes which it undergoes during chemical decay.

Orthoclase has the formula $K_2O, Al_2O_3, 6 SiO_2$, corresponding in composition to silica 64.60 per cent, alumina 18.50 per cent, potash 16.90 per cent. When exposed to the action of waters carrying in solution carbonic, sulphuric, and organic acids, a chemical decomposition of the mineral takes place, resulting in the removal of the potash and most of the silica (and of any lime or iron that may be present), the formation of a hydrous aluminum silicate, and the segregation of the residual silica. The aluminum silicate thus formed may be any one of a long series — of which kaolinite and pholerite are probably the most prominent. The chemical relationship existing between the original feldspar and these two possible final products is shown in the following comparative table.

TABLE 105. — COMPOSITION OF ORTHOCLASE, KAOLINITE, AND PHOLERITE.

	Orthoclase.	Kaolinite.	Pholerite.
Silica (SiO_2).....	64.6	46.3	39.3
Alumina (Al_2O_3).....	18.5	39.8	45.0
Potash (K_2O).....	16.9	.....	.....
Combined water.....	.....	13.9	15.7
Formula.....	$K_2O, Al_2O_3, 6 SiO_2$	$Al_2O_3, 2 SiO_2,$ + H_2O	$2 Al_2O_3, 3 SiO_2,$ + $4 H_2O$
Specific gravity.....	2.57	2.5	.....

Pure kaolinite and pholerite are plastic, highly refractory, white-burning materials. As formed by the decay of granitic rocks, however, the products are impure, containing grains or masses of the relatively insoluble constituents of the granite, i.e., quartz, mica, hornblende, etc. These impurities operate to reduce the plasticity and refractoriness of the product, and often to alter its color when burnt to yellow or even red. Of

course the less quartz and mica contained in the original rock the purer would be the product, and the ideal kaolinite (or pholerite) would therefore result from the decay of a vein of pure feldspar.

All that has been said in the above paragraphs concerning the chemical decay of feldspar must be read with the understanding that this is only one phase of the weathering of an igneous rock, and that often it is not even an important* phase. To ascribe all clay deposits, ultimately, to such an origin is simply to misunderstand the very obvious facts of the case.* Purely mechanical disintegration always plays a large part in the weathering of such rocks, and at times it is the *only* important agent. Many residual materials will be found which show little sign of chemical alterations or changes, and differ from the unweathered rock only in the fact that they are now fine, unconsolidated products instead of the original mass of interlocking crystals.

TABLE 106. — ANALYSES OF ACID IGNEOUS ROCKS AND RESIDUAL CLAYS.

	1a.	1b.	2a.	2b.
Silica (SiO_2).....	66.31	56.40	69.88	51.29
Alumina (Al_2O_3).....	18.27	25.62	16.42	29.69
Ferrous oxide (FeO) {				
Ferric oxide (Fe_2O_3) {	2.51	3.45	1.96	6.33
Lime (CaO).....	2.91	0.37	1.78	0.07
Magnesia (MgO).....	1.22	0.98	0.36	0.14
Potash (K_2O).....	4.09	2.99	5.63	1.50
Soda (Na_2O).....	3.69	1.36	4.46	1.12
Combined water.....	0.61	9.18	0.36	10.36

1a. Fresh granite }
 1b. Residual clay } Camak, Georgia. Bull. 9, Georgia Geol. Sur., p. 321.
 2a. Fresh granite }
 2b. Residual clay } Greenville, Georgia. Bull. 9, Georgia Geol. Sur., p. 315.

The character of the residual clay resulting from the decay of an igneous rock depends partly on the composition of the original rock, and partly on the degree to which decomposition has pro-

* Of recent American writers on the origin of clays, only one has treated this subject with thorough knowledge and a due sense of proportion; and the reader, desirous of making a more detailed study of this phase of the subject will, therefore, do well to consult G. P. Merrill's "Rocks, Rock Weathering, and Soils."

gressed. The effect of the second of these factors is of course obvious, but the first requires some further consideration.

The acid igneous rocks — such as the granites — are relatively high in silica, and low in iron oxide, lime, magnesia, and alkalies. The clays which result from the decomposition and disintegration of such rocks are apt, therefore, to be low in the last-named constituents.

The basic igneous rocks — traps, gabbros, etc. — being originally low in silica and relatively high in iron, lime, magnesia, and alkalies, give usually much more impure residual clays than do the acid rocks. Even when chemical action (solution) has been most thorough, much or all of the iron oxide is left behind in the clay; though the lime, magnesia, and alkalies of the original rock may appear in greatly lessened percentages in the residual material. Where mechanical disintegration has played much part in the process, however, then fluxing impurities remain in the residual product.

Basic rocks do not occur at the earth's surface in such great masses as the more acid types, nor are they so widely distributed. Because of these facts, clays derived from basic rocks are not of very common occurrence or of great importance to the clay industries.

TABLE 107. — ANALYSES OF BASIC IGNEOUS ROCKS AND RESIDUAL CLAYS.

	1a.	1b.	2a.	2b.
Silica (SiO_2).....	46.75	42.44	38.85	38.82
Alumina (Al_2O_3).....	17.61	25.51	12.77	22.61
Iron oxide (Fe_2O_3).....	16.79	19.20	12.86	13.33
Lime (CaO).....	9.46	0.37	6.12	6.13
Magnesia (MgO).....	5.12	0.21	22.58	9.52
Potash (K_2O).....	0.55	0.49	0.19	0.18
Soda (Na_2O).....	2.56	0.56	0.11	0.20
Water.....	0.92	10.92	6.52	9.21

- 1a. Fresh diorite } Albermarle County, Va. G. P. Merrill, "Rocks, Rock
 1b. Residual clay } Weathering, and Soils," p. 225.
 2a. Fresh pyroxenite } Albermarle County, Va. G. P. Merrill, "Rocks,
 2b. Residual clay } Rock Weathering, and Soils," p. 226.

Residual from Decay of Shales or Slates. — Since shales and slates are formed simply by the consolidation of clay beds, it is obvious that simple mechanical disintegration of a bed of shale

will cause it to again become a bed of clay. So that wherever shale beds are exposed to weathering we find that along the outcrop the shales have broken down and become soft and plastic. Often the change has gone further than simple disintegration, for during the physical decay of the shale percolating waters may have removed some of its more soluble constituents.

TABLE 108. — ANALYSES OF CLAYS RESIDUAL FROM SHALE.

	1.	2.	3.	4.	5.
Silica (SiO_2).....	71.91	73.30	84.05	72.16	47.00
Alumina (Al_2O_3).....	16.24	14.49	9.44	21.76	38.75
Iron oxide (Fe_2O_3).....	1.79	1.26	0.28	0.99	0.95
Lime (CaO).....	0.18	0.19	0.23	0.22	0.70
Magnesia (MgO).....	0.88	2.14	1.35	0.70	tr.
Alkalies (K_2O , Na_2O).....	3.27	4.31	2.65	5.14	tr.
Carbon dioxide (CO_2).....					
Combined water.....	4.39	3.57	2.18	4.76	12.94

1. Hot Springs, Ark. Average of four analyses by Geo. Steiger. Bull. 285, U. S. Geol. Sur., p. 409.
2. Mountain Valley, Ark. Average of two analyses by Geo. Steiger. Bull. 285, U. S. Geol. Sur., p. 409.
3. Upper Mill, Pa. Hopkins, Clays of Pennsylvania, pt. 3, p. 10.
4. Fogelsville, Pa. Hopkins, Clays of Pennsylvania, pt. 3, p. 10.
5. Valley Head, Ala.

Clays formed by the decay of beds of shale or slate are apt to contain little foreign matter except, perhaps, an occasional fragment of unweathered shale. Of course these fragments are rare near the surface but become more common in the deeper parts of the clay deposit, as the unweathered portion of the rock is approached. Even where frequent, however, they do not injure the value of the deposit, for the unweathered fragments of shale are of practically the same composition as the bed of residual clay which is derived from the weathering of the shale.

The form taken by such deposits of clay (i.e. residual from shales or slates), depends largely on the attitude of the original shale bed and on the topography of the district. If the shale bed was highly inclined to the horizon and outcropped along a hillside (as in Fig. 24), percolating water and atmospheric agencies might

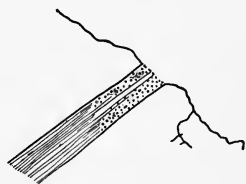


Fig. 24.—Inclined shale bed weathered to clay.

readily disintegrate the shale for some distance down from the outcrop. The resulting clay deposit would still be in the form of a bed, with a dip corresponding to that of the original shale bed.

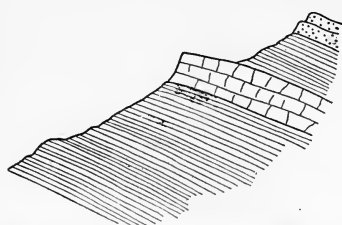


Fig. 25. — Interbedded shales and limestone.

In one particular case, however, a very marked change in attitude may be brought about by the weathering of the rocks; and this special case is of much importance since it has given rise to many valuable clay deposits in southeastern Pennsylvania, in

Alabama, and elsewhere. The case in question is when the shale was originally interbedded with limestone, both series of rocks dipping at an angle of 15 degrees to 50 degrees. The effect of weathering on such an outcrop is twofold, for while the shale weathers into clay, most of the limestone is dissolved, so that the soft clay beds gradually sink down to



Fig. 26. — Effect of weathering on shale-limestone strata.

form a thick and irregularly-shaped deposit. This deposit contains not only the softened shale, but also any insoluble material that was contained in the original limestone. When such a clay deposit is examined, therefore, masses of fairly pure shale clay will be found inclosing layers of less pure and limestone residual, often containing fragments or nodules of chert or flint.

If the shale bed had been horizontal or nearly so, and were now exposed along a valley bottom, the clay deposit would probably be more irregular in thickness, as indicated in Fig. 27.



Fig. 27. — Horizontal beds of shale-clay.

For in this case the depth of disintegration of the shale would depend more on accidental features, such as the existence of joint planes, thinness of soil cover, etc.

An interesting and somewhat exceptional case of the formation of a high-grade residual clay from sandstone has recently been noted by Loughlin.* The occurrence is at West Cornwall, Litchfield County, Connecticut, where a highly feldspathic sandstone has decayed in place. The resulting product is a mixture of quartz grains and a very pure residual clay or "kaolin." Of course the material requires washing, in order to free the clay from the sand. An analysis of the washed product gave the following results:

Silica (SiO_2)	47.50
Alumina (Al_2O_3)	37.40
Iron Oxide (Fe_2O_3)	0.80
Lime (CaO)	tr.
Magnesia (MgO)	0.00
Alkalies (K_2O , Na_2O)	1.10
Water	12.48

Residual from Decay of Limestones. — The formation of residual clays from limestones is a process of peculiar interest, not only because it has given rise to many large clay deposits, but because certain factors enter into the question which are absent from the decay of igneous rocks and shales.

Limestones are composed † *essentially* of lime carbonate, or of a mixture of lime and magnesium carbonates. Some contain little else than these carbonates, but by far the majority of limestones carry appreciable percentages of clayey matter (silica, alumina, and iron) and often other impurities (sulphur, alkalies, etc.). Most of these impurities — and particularly the clayey materials — are very insoluble, as compared to lime and magnesium carbonates. The latter are readily attacked by water carrying dissolved carbon dioxide. When a bed of limestone is permeated by waters so charged, the carbonates of lime and magnesia are carried off in solution, while any clayey matter which may have been contained in the limestone is left behind. Long exposure to such action will result in the removal of a vast amount of limestone, and in the accumulation of a great thickness of residual material (clay, chert, etc.), as a mantle over the remnant of the limestone, even when the original limestone

* Clays and Clay Industries of Connecticut, pp. 15, 30, 31, etc.

† For a more detailed discussion of the composition of limestones, reference should be made to pages 152-155.

contained very small amounts (1 to 3 per cent) of such clayey matter.

An example may make the case clearer. Suppose that a horizontal bed of limestone 100 feet thick, whose composition is

	Per cent.
Silica.....	2½
Alumina.....	1½
Iron oxide.....	1
Lime carbonate.....	95

(this would really be a limestone above the average in purity), were attacked by percolating water, charged with carbon dioxide,

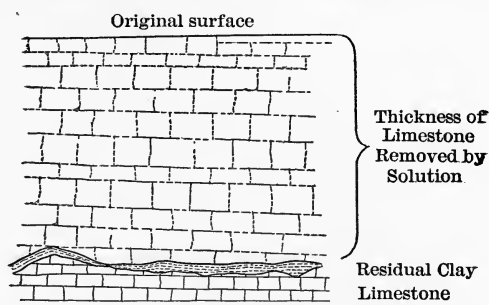


Fig. 28. — Formation of residual clay from limestone.

the lime carbonate would be removed in solution, while the insoluble matter would be left behind. In place of the original 100-foot bed of limestone, there would remain a 5-foot bed of clay of approximately the composition, silica 50 per cent, alumina 30 per cent, iron oxide 20 per cent. Now in many cases the conditions have been even more favorable to clay formation than in the case supposed, for the original limestones have been both thicker and more impure.

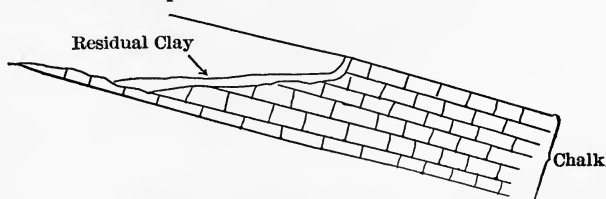


Fig. 29. — Residual clays from chalk.

The effect of such weathering on an inclined series of chalky limestones is shown in Fig. 27.

Another excellent example of a deposit of clay residual from limestone is illustrated in Fig. 28. This shows a section across such a deposit at Bertha, Va. The blocked area in the section is limestone, containing only a very small percentage of clayey matter. By its solution, however, a very great thickness of residual clay is accumulated, and this caps the remaining limestone as shown in the figure. A point of particular interest is

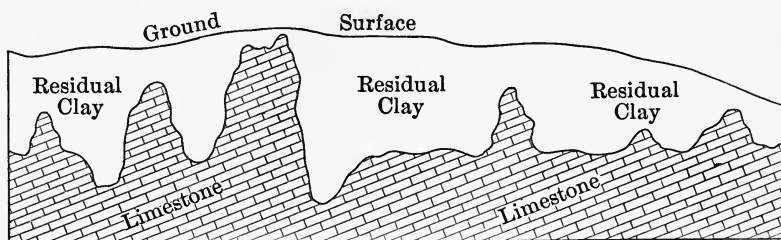


Fig. 30. — Residual clays from limestone.

the very irregular form of the base or floor of the clay deposit. It will be seen that the limestone has been dissolved so irregularly as to leave pillars and bosses projecting upward into the clay. Such a deposit must of necessity be drilled very carefully in order to determine the available tonnage. Another point brought out by the figures is the sharpness of the transition from clay to unaltered limestone. The whole process is one of solution, so that clays residual from limestone do not show the gradual change downward into the parent rock which is characteristic of clays residual from igneous rocks or from shale.

Clays derived from the decay of limestones are commonly very fine-grained, and consequently very fat or plastic. The clay itself is apt to be rather low in silica; but the clay deposit frequently contains nodules of chert or flint, or masses (large or small) of iron pyrite or brown iron ore. These materials are as insoluble as the clay, and like it are left behind when the limestone is dissolved. On the other hand, the limestone clays do not ordinarily contain sand, gravel, or pebbles.

A typical series of such clays is presented below in Table 109, which may be profitably compared with the analyses already given in Table 108.

TABLE 109. — ANALYSES OF CLAYS RESIDUAL FROM LIMESTONE.

	1.	2.	3a.	3b.
Silica (SiO_2).....	55.42	43.37	0.42	48.96
Alumina (Al_2O_3).....	22.17	25.07	0.22	26.27
Iron oxide (Fe_2O_3).....	8.30	15.16	0.19	10.53
Lime (CaO).....	0.15	0.63	29.77	0.24
Magnesia (MgO).....	1.45	0.03	20.69	1.02
Alkalies (K_2O , Na_2O).....	2.49	3.70	0.80	n.d.
Carbon dioxide (CO_2).....	.....	.....	44.43	n.d.
Water.....	9.86	12.98	3.41	9.47

1. Morrisville, Calhoun County, Ala. }
 2. Lexington, Va. } Bull. 52, U. S. Geol. Sur., p. 40.
 3a. Limestone }
 3b. Residual clay } Austinville, Va.; Bull. No. 1, Va. Geol. Sur., p. 98.

CHAPTER XV.

TRANSPORTED CLAYS.

Origin of Transported Clays. — The transported clays differ from the residual clays principally in having been moved from the locality at which they were formed, so that their point of deposit may be far from their point of origin. This transportation may have been effected through the agency of running water, of glacial ice, or of the wind. The first of these agents, however, is by far the most common transporting power; ice has moved very few clays, while the effect of wind is in reality a very open question.

WATER-BORNE OR SEDIMENTARY CLAYS.

According to their point of deposition the sedimentary clays are subdivided into stream, lake, and marine.

Marine Clays. — The material carried by streams and rivers to the ocean is spread out finally in estuaries, in marshes along the coast line, or as a mantle over the ocean depths. In all these cases the finer material is, of course, carried the farthest, and is deposited only at points where the force of the transporting current is checked.

No very sharp line can be drawn between certain classes of marine and stream clays, for clays deposited in the delta of a river, in a broad, shallow estuary or bay, or in marshes along the coast could with much reason be considered fresh-water rather than marine, though in the present volume they are for convenience included with the true marine clays.

Marine Clays Proper. — Most of the marine clays which are forming at the present day are, of course, unavailable for commercial uses, for they are mostly covered by the waters of the ocean. But marine clays formed during earlier geologic periods are of great importance, for earth movements have often elevated the ocean basins or ocean shores so that many marine sediments are now exposed at the earth's surface. Owing to long-continued

exposure to heat and pressure of the clays so elevated, the older ones have generally become hardened so that they now appear in the form of shales or slates, rather than as ordinary soft plastic clays. The more recently elevated marine clays, however, still retain their softness and plasticity, as is notable in the clay deposits of the coastal plain.

TABLE 110. — ANALYSES OF MARINE CLAYS.

	1.	2.	3.
Silica (SiO_2).....	62.80	62.33	61.59
Alumina (Al_2O_3)*.....	18.23	18.49	19.10
Iron oxide (Fe_2O_3 , FeO).....	6.40	6.91	7.53
Lime (CaO).....	0.88	1.00	1.68
Magnesia (MgO).....	1.58	1.53	1.87
Potash (K_2O).....	3.05	2.41	n.d.
Soda (Na_2O).....	1.48	2.38	n.d.
Combined water.....	4.39	3.81	5.51
Moisture.....	1.31	1.11	

* Including small percentages of titanic oxide (TiO_2).

1. Thomaston, Me.
2. Hayden's Pt., South } W. T. Schaller, analyst.
Thomaston, Me.
3. Rockland, Me.

Shales. — It has been noted previously that *shales* are simply clays which have been hardened by pressure. This statement, while approximately correct, requires some restriction for our present purposes. For shales have been derived almost entirely from extensive deposits of clays of marine origin — deposited along seacoasts or in large basins — and such marine deposits will naturally differ considerably from glacial, stream, or lake clays. The marine clays have, in general, been transported further than the other types of clay, and have been more effectively sorted while in transit. For this reason the shales derived from them rarely show the same irregularities in physical composition that some modern clays exhibit. Shales, for example, are rarely so full of coarse sand, gravel, limestone fragments, etc., as are the glacial clays of the northern states. Sandy shales and limy shales do occur, it is true, but even in this case such impurities are usually more regularly distributed throughout the mass of the rock than is the case with the impurities of the glacial clays.

The limy shales are almost exclusively shales which occur interbedded, in comparatively thin layers, with limestones. Occasionally a limy shale will owe its content of lime almost entirely to the fossil shell it contains, the remainder of the shale being practically free from carbonates. For both of the above reasons limy shales are apt to be a source of trouble in the practical working of a plant and require considerable care in quarry management to insure that the raw materials are anywhere near uniform in composition from day to day.

Slates. — Slates* are clays or shales which have been so hardened and otherwise affected by pressure as to have taken on a regular parallel cleavage, being thus capable of being readily split into thin tough plates. The origin, composition, and distribution of slates have been discussed in detail elsewhere in this volume (Chapter VII). Their interest in the present connection is due to the fact that large quantities of waste slate are produced in the operations of quarrying and dressing roofing or mill slate, and that much of this waste could be utilized in the manufacture of clay products.

Stream Clays. — A stream carrying sediments will deposit a portion of its load at points where its current is checked. This is likely to occur in the broader and shallower reaches of its course, and is particularly frequent when floods have caused the stream to overflow its banks. In this last case the sediment is deposited, levee fashion, parallel to the course of the stream.

In dealing with the clays deposited along the larger streams, it will frequently be found that they occur in the form of district terraces, or flat-topped benches, and that often there will be several pairs of such terraces, each at a different elevation. Any one of several causes may have produced this arrangement, but the frequency of the arrangement itself is worth bearing in mind.

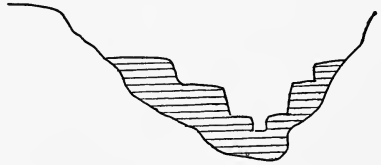


Fig. 31. — Clay terraces.

* It may here be noted that geologists restrict the term slate to clay rocks in which the cleavage has been developed at some angle to the original bedding planes. In common use, however, any shale which breaks into flat and fairly even plates is called a slate, regardless of the direction of the faces of these plates.

A very typical set of terrace-clay deposits is shown in Fig. 32, reprinted from the paper by Jones later cited (page 252). The deposits shown in this figure are those occurring along the Hudson River at many points on both of its banks, though in the figure only a few deposits on the east bank are presented.

TABLE 111. — ANALYSES OF STREAM CLAYS.

	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron oxides (Fe ₂ O ₃ , FeO).	Lime (CaO).	Mag- nesia (MgO).	Potash (K ₂ O).	Soda (Na ₂ O)	Carbon dioxide (CO ₂).	Com- bined water.
1	52.73	22.25	7.69	1.48	3.20	4.28	2.22	4.91	
2	50.33	27.06	4.91	1.22	3.34	4.40	1.78	5.24	
3	55.27	20.52	6.89	2.21	2.80	3.43	2.82	5.06	
4	51.10	17.65	6.47	7.45	0.87	n.d.	n.d.	n.d.	n.d.
5	50.60	21.00	7.35	3.75	0.96	n.d.	n.d.	n.d.	n.d.
6	59.81	22.00		4.35	2.29	n.d.	n.d.	n.d.	7.89

- | | | |
|-----------------------------|--|---------|
| 1. South Windsor, Conn. | } W. T. Schaller, analyst; Bull. 4, Conn. Geol. Sur., p. 59. | |
| 2. West Hartford, Conn. | | |
| 3. Newfield, Conn. | | |
| 4. Coeyman's Landing, N. Y. | } Bull. 35, N. Y. State Museum. { | p. 705. |
| 5. Catskill, N. Y. | | p. 702. |
| 6. Barrytown, N. Y. | | p. 702. |

Lake Clays. — Streams flowing into lakes or ponds tend to deposit their sediment at the point where their flow is checked. In small lakes, therefore, the heavier sediments are commonly deposited where the stream enters the lake, while the drier clayey deposits occur a little further off shore.

In lakes large enough to be seriously affected by wind and current action, the distribution and character of the clay deposits are closely similar to those of marine clays.

Ice-borne or Glacial Clays. — The finer material transported by glacial ice, and deposited along or near the margin of the glacier, often forms clay deposits of commercial importance. Owing to the purely mechanical origin of clays of this type, they commonly contain fragments of limestone, sand, pebbles, etc., which limit their use to the manufacture of low-grade products.

Wind-borne or Eolian Clays. — Many geologists consider that the vast deposits of loess which border the Mississippi and other great rivers are of eolian origin, the material having been transported by the wind.

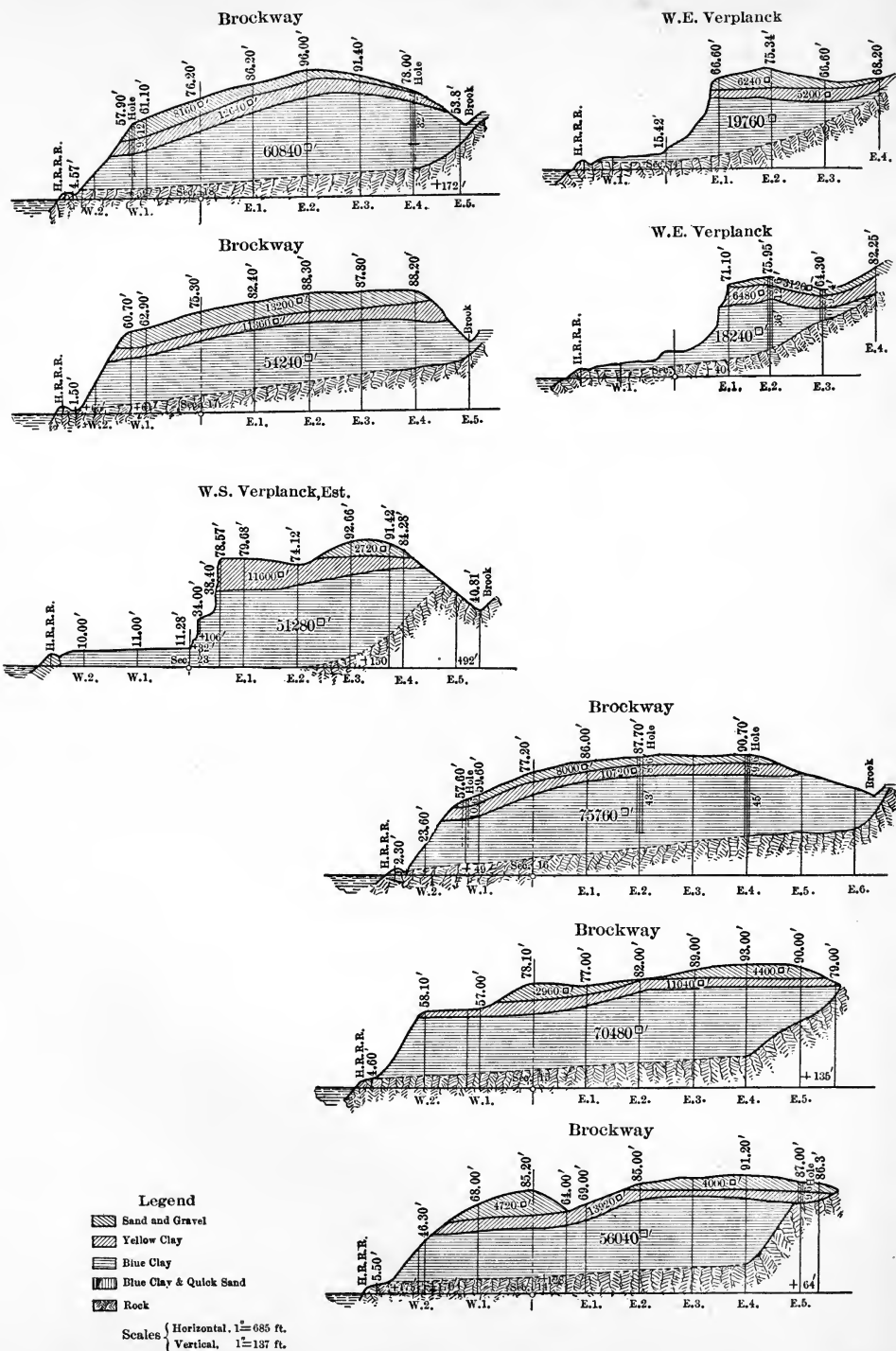


Fig. 32. — Clay terraces along Hudson River. (C. C. Jones.)

The loess clays from various points along the Mississippi are strikingly uniform in composition, the range of the principal elements being slight. The following series of analyses illustrate this point.

TABLE 112. — ANALYSES OF LOESS CLAYS.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2).....	72.00	71.11	74.39	73.80	73.92	67.92
Alumina (Al_2O_3).....	11.97	11.62	12.03	13.19	11.65	11.76
Iron oxide (Fe_2O_3).....	3.51	3.90	4.06	3.43	4.74	6.72
Lime (CaO).....	1.80	2.37	1.50	0.86	1.43	1.63
Magnesia (MgO).....	1.35	1.47	1.53	0.68	0.60	1.18
Alkalies (K_2O , Na_2O).....	3.25	3.14	3.01	2.94	3.13	3.79
Combined water.....	6.42	6.71	3.17	5.26	3.08	5.36
Specific gravity.....	2.17	2.20	2.09	2.17	1.98	.....

1. Kansas City.
2. Boonville.
3. Jefferson City.

4. Hannibal.
5. St. Louis.
6. Gladbrook, Iowa.

List of References on Origin of Clays:

- Barus, C. On the thermal effect of the action of aqueous vapor on feldspathic rocks (kaolinization). *School of Mines Quarterly*, vol. 6, pp. 1-24. 1885.
- Bulman, G. W. Underclays: a preliminary study. *Geol. Mag.*, new series, decade III, vol. 9, pp. 351-361. 1892.
- Cook, G. H. Report on the clay deposits of New Jersey, 1878, pp. 267-306.
- Cushman, A. S. On the cause of the cementing value of rock powders and the plasticity of clays. *Jour. Amer. Chem. Soc.*, vol. 25, pp. 451-468. 1903.
- Hopkins, T. C. A short discussion of the origin of the coal measures fire clays. *Amer. Geol.*, vol. 28, pp. 47-51. 1901.
- Hopkins, T. C. Fire clays of the coal measures. *Mines and Minerals*, vol. 22, p. 596. 1902.
- Hopkins, T. C. Kaolin: its occurrence, technology, and trade. *Min. Ind.*, vol. 7, pp. 148-160. 1899.
- Hutchings, W. M. Further notes on fire clays, etc. *Geol. Mag.*, new series, decade III, vol. 8, pp. 164-169. 1891.
- Hutchings, W. M. Rutile in fire clays. *Geol. Mag.*, new series, decade III, vol. 8, pp. 304-306. 1891.
- Hutchings, W. M. Notes on sediments dredged from the English lakes. *Geol. Mag.*, new series, decade IV, vol. 1, pp. 300-302. 1894.
- Irving, R. Kaolin in Wisconsin. *Trans. Wis. Acad. of Sci.*, vol. 3, pp. 3-30. 1876.

- Johnson, S. W., and Blake, J. M. On kaolinite and pholerite. *Amer. Jour. of Sci.*, vol. 43, p. 351. 1876.
- Merrill, G. P. A Treatise on Rocks, Rock-Weathering, and Soils, 8vo, 411 pages, Macmillan & Co., New York. 1897.
- Merrill, G. P. What constitutes a clay. *Amer. Geol.*, vol. 30, pp. 318-322. 1902.
- Orton, E. The clays of Ohio, their origin, composition, and varieties. *Rep. Ohio Geol. Sur.*, vol. 7, pp. 45-68. 1893.
- Ries, H. The origin of kaolin. *Trans. Amer. Ceramic Soc.*, vol. 2. 1900.
- Wheeler, H. A. Clay deposits of Missouri. *Rep. Missouri Geol. Sur.*, vol. 11, pp. 17-27, 49-114. 1896.

CHAPTER XVI.

DISTRIBUTION OF CLAYS.

Geographic Distribution of Clays.—In a volume of this size little of value can be said concerning the *local* distribution of clays, but a few general statements will be made which may serve as a guide to exploration or to further study of the matter. Certain large areas can at least be roughly defined, within each of which areas a certain class of clay predominates. If the reader desires details regarding the distribution of clays in any particular state, or smaller area, reference should of course be made to the reports listed on pages 240-243.

The glaciated area lies to the north of the line which marks the extreme southern limit attained by the great ice sheets. North of this line the bedrock was swept clear of all its overlying débris by the glaciers, and except in a few instances no large amount of postglacial decay has occurred. Residual clays are therefore practically lacking in the glaciated area.

The coastal plain is the term applied by geologists and physiographers to the great belt of lowland that, from New York City southward, borders the Atlantic and Gulf coasts. Its eastern and southern limits are, of course, the shores of the Atlantic and the Gulf of Mexico. Its western and northern limits may be located closely by tracing a line from New York City through Trenton, Philadelphia, Baltimore, and Washington.

The clays of the coastal plain are mostly of marine origin, having been deposited at a time when the coast line was just inland of their present location. They are therefore more widely distributed than glacial or stream clays and their general character and location can usually be predicted, with some certainty, in advance of actual exploration.

The coastal plain clays are usually quite siliceous, and low in lime, magnesia, and alkalies. They furnish pottery, stoneware, and firebrick clays, the pottery clays of New Jersey and the

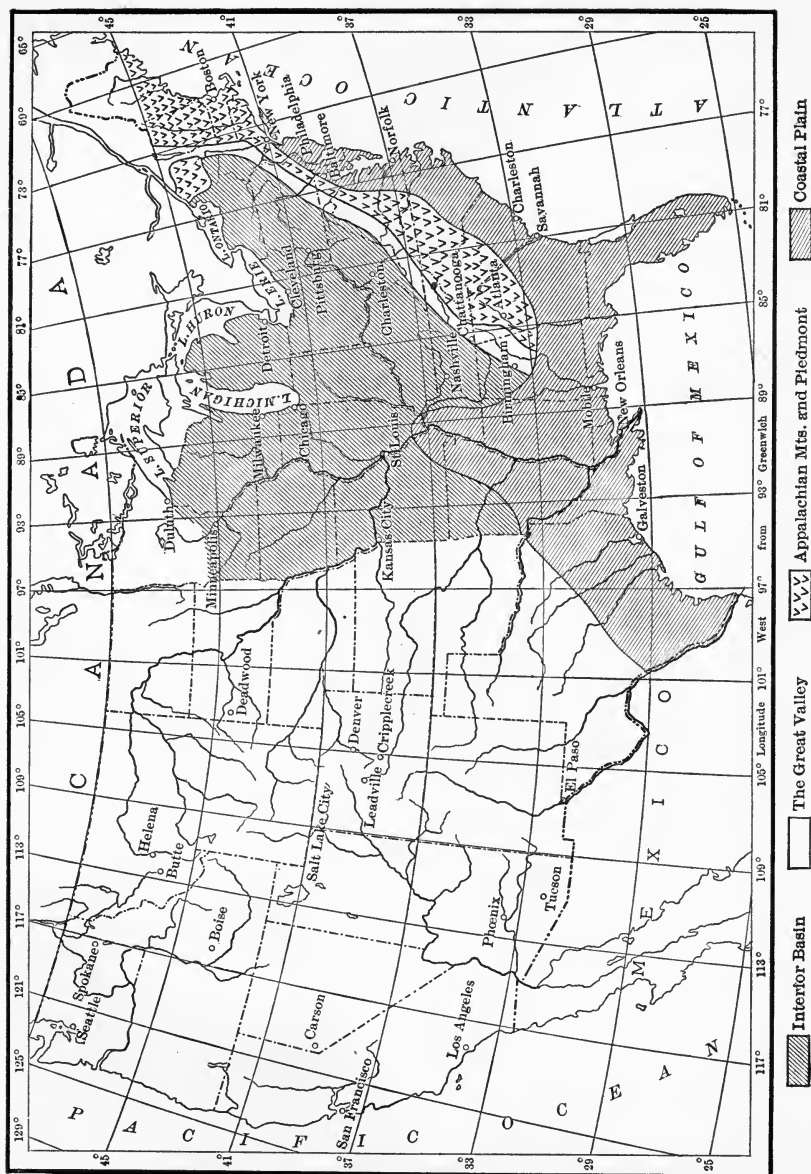


Fig. 33. — Physiographic Region of Eastern United States.

stoneware clays of northern Mississippi and western Tennessee and Kentucky being worthy of special note.

In the elevated Piedmont and Appalachian regions which lie inland of the Coastal Plain, the decay of igneous and metamorphic rocks has given rise to bodies of residual clays. These differ in size and grade according to the rocks from which they are derived.

The region northwest of the Blue Ridge (and its northern and southern continuations) is covered by old sedimentary rocks — sandstones, limestones, and shales. Here again a distinction is to be made between the regions north and south of the glacial border.

In the great Appalachian Valley which parallels the western flank of the Blue Ridge or Appalachian range, deep weathering of limestone and shale beds has given rise to heavy deposits of residual clay, particularly south of the glacial limit.

The plateau west of the Great Valley yields chiefly shales, varying widely in their character and commercial value.

List of References on the Distribution of Clays and Shales. — The literature of clays is so extensive that the descriptive papers in the following list have been arranged by States in alphabetical order.

General United States:

- Ries, H. The clays of the United States east of the Mississippi River. Professional Paper No. 11, U. S. Geol. Sur., 289 pp. 1903.

Alabama:

- Ries, H., and Smith, E. Preliminary report on the clays of Alabama. Bull. 6, Ala. Geol. Sur., 220 pp. 1900.

Arkansas:

- Branner, J. C. The cement materials of southwest Arkansas. Trans. Am. Inst. Min. Engrs., vol. 27, pp. 42-63.
Branner, J. C. The clays of Arkansas. Bull. No. —, U. S. Geol. Sur. (In press.)

California:

- Johnson, W. D. Clays of California. 9th Ann. Rep. Cal. State Min., pp. 287-308. 1890.
Ries, H. The clay-working industry of the Pacific Coast States. Mines and Minerals, vol. 20, pp. 487-488. 1900.

Colorado:

- Lakes, A. Gypsum and clay in Colorado. Mines and Minerals, vol. 20. December, 1899.
Ries, H. The clays and clay-working industry of Colorado. Trans. Am. Inst. Min. Engrs., vol. 27, pp. 336-340. 1898.

Florida:

- Memminger, C. J. Florida kaolin deposits. Eng. and Min. Jour., vol. 57, 436 pp. 1894.
Vaughan, T. W. Fuller's earth deposits of Florida and Georgia. Bull. 213, U. S. Geol. Sur., pp. 392-399. 1903.

Georgia:

- Ladd, G. E. Preliminary report on a part of the clays of Georgia. Bull. 6A, Ga. Geol. Sur., 204 pp. 1898.
Vaughan, T. W. Fuller's earth deposits of Florida and Georgia. Bull. 213, U. S. Geol. Sur., pp. 392-399.

Indiana:

- Blatchley, W. S. A preliminary report on the clays and clay industries of the coal-bearing counties of Indiana. 20th Ann. Rep. Ind. Dept. Geol. and Nat. Res., pp. 24-187. 1896.
Blatchley, W. S. Clays and clay industries of northwestern Indiana. 22d Ann. Rep. Ind. Dept. Geol. and Nat. Res., pp. 105-153. 1898.

Iowa:

- Beyer, S. W., and others. Clays and clay industries of Iowa. Vol. 14, Rep. Iowa Geol. Sur., pp. 27-643. 1904.

Kansas:

- Prosser, C. S. Clay deposits of Kansas. Min. Res. U. S. for 1892, pp. 731-733. 1894.

Kentucky:

- Crump, H. M. The clays and building stones of Kentucky. Eng. and Min. Jour., vol. 66, pp. 190, 191. 1898.

Louisiana:

- Clendennin, W. W. Clays of Louisiana. Eng. and Min. Jour., vol. 66, pp. 456, 457. 1898.
Ries, H. Report on Louisiana clay samples. Rep. La. Geol. Sur. for 1899, pp. 263, 275. 1900.

Maryland:

- Ries, H. Report on the clays of Maryland. Rep. Md. Geol. Sur., vol. 4, pt. 3, pp. 203-507, 1902.

Massachusetts:

- Whittle, C. L. The clays and clay industries of Massachusetts. Eng. and Min. Jour., vol. 66, pp. 245, 246, 1898.

Michigan:

- Ries, H. Clays and shales of Michigan. Rep. Mich. Geol. Sur., vol. 8, pt. 1, 67 pp. 1900.

Minnesota:

- Berkey, C. P. Origin and distribution of Minnesota clays. Am. Geol., vol. 29, pp. 171-177. 1902.

Mississippi:

- Crider, A. F. Clays of Mississippi. Bull. 1, Miss. Geol. Surv.
Eckel, E. C. Stoneware and brick clays of western Tennessee and north-western Mississippi. Bull. 213, U. S. Geol. Sur., pp. 382-391. 1903.

Missouri:

Wheeler, H. A. Clay deposits of Missouri. Rep. Mo. Geol. Sur., vol. 2, 622 pp. 1896.

Montana:

Rowe, J. P. The Montana clay industry. Brick, vol. 24, pp. 1-3. Jan., 1906.

Nebraska:

Gould, C. N., and Fisher, C. A. The Dakota and Carboniferous clays of Nebraska. Ann. Rep. for 1900, Neb. Bd. of Agric., pp. 185-194. 1901.

New Jersey:

Cook, G. H., and Smock, J. C. Report on the clay deposits of New Jersey. N. J. Geol. Sur., 381 pp. 1878.

Ries, H., Kummel, B., and Knapp, G. N. The clays and clay industries of New Jersey. Final Rep. State Geol., N. J., 8vo., vol. 6, 548 pp. 1904.

New York:

Jones, C. C. A geologic and economic survey of the clay deposits of the lower Hudson River Valley. Trans. Am. Inst. Min. Engrs., vol. 29, pp. 40-83. 1900.

Ries, H. Clays of New York. Bull. 35, N. Y. State Museum, 455 pp. 1900.

North Carolina:

Holmes, J. A. Notes on the kaolin and clay deposits of North Carolina. Trans. Am. Inst. Min. Engrs., vol. 25, pp. 929-936. 1896.

Ries, H. Clay deposits and clay industry in North Carolina. Bull. 13, N. C. Geol. Sur., 157 pp. 1897.

North Dakota:

Babcock, E. J. Clays of economic value in North Dakota. 1st Rep. N. D. Geol. Sur., pp. 27-55. 1901.

Ohio:

Orton, E. The clays of Ohio and the industries established upon them. Rep. Ohio Geol. Sur., vol. 5, pp. 643-721. 1884.

Orton, E. The clays of Ohio: their origin, composition, and varieties. Rep. Ohio Geol. Sur., vol. 7, pp. 45-68. 1893.

Oregon:

Ries, H. The clay-working industries of the Pacific Coast states. Mines and Minerals, vol. 20, pp. 487-488. 1900.

Pennsylvania:

Hopkins, T. C. Clays of western Pennsylvania. Appendix to Ann. Rep. Pa. State Coll. for 1897-98, 184 pp. 1898.

Hopkins, T. C. Clays of southeastern Pennsylvania. Appendix to Ann. Rep. Pa. State Coll. for 1898-99, 76 pp. 1899.

Hopkins, T. C. Clays of the Great Valley and South Mountain areas. Appendix to Ann. Rep. Pa. State Coll. for 1899-1900, 45 pp. 1900.

Woolsey, L. H. Clays of the Ohio Valley in Pennsylvania. Bull. 225, U. S. Geol. Sur., pp. 463-480. 1904.

South Carolina:

Sloan, E. A preliminary report on the clays of South Carolina. Bull. 1, S. C. Geol. Sur., 171 pp. 1904.

South Dakota:

Todd, J. E. The clay and stone resources of South Dakota. Eng. and Min. Jour., vol. 66, pp. 371. 1898.

Tennessee:

Eckel, E. C. Stoneware and brick clays of western Tennessee and northwestern Mississippi. Bull. 213, U. S. Geol. Sur., pp. 382-391. 1903.

Texas:

Kennedy, W. Texas clays and their origin. Science, vol. 22, pp. 297-300. 1893.

Washington:

Landes, H. Clays of Washington. Rep. Washington Geol. Sur., vol. 1, pt. 2, pp. 13-23. 1902.

Wisconsin:

Buckley, E. R. The clays and clay industries of Wisconsin. Bull. 7, Wis. Geol. Sur., 304 pp. 1901.

Irving, R. Kaolin in Wisconsin. Trans. Wis. Acad. Sci., vol. 3, pp. 3-30. 1876.

Wyoming:

Knight, W. C. The building stones and clays of Wyoming. Eng. and Min. Jour., vol. 66, pp. 546, 547. 1898.

CHAPTER XVII.

FIELD EXAMINATION OF CLAY DEPOSITS.

THE data obtained in the course of a field examination should cover the amount of clay present, its character from a technologic point of view, and such other features (drainage, stripping, transportation) as will affect the commercial value of the deposit. These field data will of course have to be supplemented by laboratory tests on the samples obtained.

The engineer called upon to examine and report upon a clay property will do well to realize that the problem before him is one which properly falls largely within the domain of applied geology. The form and extent of the clay deposits are, it is true, determined by engineering means, but the proper interpretation of the data afforded by the pits, trenches, or drill holes will usually require a working knowledge of general geologic principles. These principles are not difficult to understand, nor are they hard to apply.

The subject of field examination might naturally be divided into two parts: (1) the purely mechanical portion, relating to methods of drilling, boring, etc., and (2) the geologic portion, relating to the interpretation of the data so obtained, for this is the order in which any particular piece of work would be taken up. But in discussing the subject it is more convenient to almost reverse this arrangement, by describing first the general conduct of the work, and then taking up the methods of getting the data.

THE GENERAL CONDUCT OF FIELD WORK.

The Use of Geological Reports. — Before taking the field it is advisable to find out whether or not geological reports on the district have been published. The federal government and most states support geological surveys, and in many cases it will be found that these organizations have published more or less complete reports on either the general geology or the clay re-

sources of the district which is to be examined in detail by the engineer. Many such reports are listed on pages 240-243 of this volume.

The help to be gained from these geological reports will depend largely on the state in which the deposit is located.

Very detailed and generally satisfactory reports on clays have been issued by the states of Alabama, Connecticut, Indiana, Iowa, Maryland, Michigan, Missouri, New Jersey, New York, North Carolina, Ohio, South Carolina, and Wisconsin. Partial or otherwise incomplete reports have been issued for Georgia, Mississippi, North Dakota, Pennsylvania, South Dakota, and Washington. Scattered data of some value are on record for Arkansas, California, Florida, Kansas, Kentucky, Louisiana, and other states. Detailed reports on part or all of the clays of Arkansas, Illinois, Virginia, and Texas are known to be in preparation at the date of writing.

These reports vary greatly in their detail and value. Even the poorest of these reports, however, will contain information that will save needless labor.

Effect of Kind of Clay on Methods of Work. — The material to be reported on may be (1) a hard shale, even on its outcrop; (2) a shale which has weathered so as to appear soft and claylike; (3) an ordinary soft plastic clay, or (4) a residual "kaolin" derived from a mass or dike of decomposed granite or feldspar. Each of these types will present different problems, and may require different methods of field work.

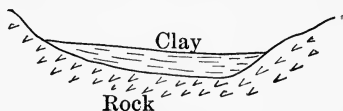


Fig. 34.

The importance of first determining the method of origin of the deposit lies in the fact that it influences both the form of the deposit and the character of the material. If the material is merely a soft surface clay, then we may expect to find a flat-lying and basin-shaped deposit, and our only interest in the hard rocks of the region will arise from the fact that they may form the lower boundary and sides of the deposit. But if the material is a shale, the dip and strike of other beds of hard rock will probably prove of interest, for we may fairly expect the shale deposit to agree in these particulars with adjacent beds of limestone, sandstone, etc.

A case in point may be cited in which the owner insisted that the ridge in which the clay occurred was composed entirely of high-grade clay — a thickness of 800 feet or more being claimed. The statement was inherently improbable, owing to the geologic structure of the region, but the property was visited. A large number of pits had been run in on clay at various elevations on both flanks of the ridge, and a shallow trench had been cut transversely across the top of the ridge. The trench and all the pits showed clay, and the owner pointed to this triumphantly as proving his statement. Outcrops were scarce, as both top and flanks of the ridge were well covered with soil and tim-

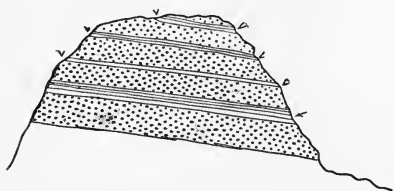


Fig. 35. — Interbedded sandstones and shale-clays.

ber, but several carefully measured sections, made at various points, when combined showed that the conditions were as in Fig. 35. In place of a solid bed of clay 800 feet thick there were in reality a number of clay beds, one 30 feet thick but most of them varying from 4 inches to 3 feet — the total

thickness of *all* the clay beds was not over 60 feet, and the remaining 770 feet was sandstone. But the case was even worse than this. In looking over the face cut into the 30-foot clay bed, a number of beds of loose sand were noticed. Careful examination showed that the clays were really the exposed weathered outcrops of a series of shales, that the sands were similarly weathered sandstones, and that consequently when the workings were driven in under cover the owner might expect to find, in place of the 30-foot clay bed exposed at the outcrop, a series of shale beds interbedded with sandstones, and that these shales would probably contain impurities which had been removed by weathering from the clays which showed at the outcrop.

Now in this case all this information could have been obtained directly, but only at prohibitive expense, by deep drilling across the ridge. Handling it purely as an engineering problem would have required several months' work and the expenditure of several thousand dollars, while by the application of purely geologic methods of reasoning and field work the same results were secured in less than a day.

Examination of Shale Deposits. — Shales are mostly of marine origin, and were deposited in extensive water areas. Any given bed of shale is therefore apt to be quite regular both in thickness and in composition, for considerable distances. This materially lessens the labor of the explorer. If on visiting a property he finds, for example, a good outcrop which shows a 30-foot bed of shale underlain by a bed of limestone and overlain by strata of sandstone, he may be fairly sure that this shale bed will probably not vary greatly in thickness or in its associated rocks within the limits of the property. It would be fair to expect that its thickness will not fall below 25 or rise above 35 feet in a quarter mile. It would also be a reasonable expectation — and this is a matter of great value — that if at some near-by point he finds the limestone outcropping, with perhaps a soil-covered slope above it, trenching above the limestone would reveal the shale in its proper position. An outcrop of the overlying sandstone, on the other hand, would lead the engineer to trench on the slope below it in order to uncover the shale bed.

In this connection it is well to recollect that in most of the shale-producing areas of the United States the rocks are lying in an almost horizontal attitude. If a shale bed outcrops in the flank of a ridge, the shale is apt to weather so as to produce quite steep but regular slopes, usually slippery because covered with loose fragments of shale. Sandstone or heavy limestone beds, under similar conditions, would be apt to form very marked terraces or stepped slopes. These conditions are well shown in Fig. 25, which is a drawing to scale. Here a sandstone bed forms the crest of the ridge, a limestone bed forming a very marked terrace about one-third of the way down the slope, while the shale beds above and below the limestone give the usual shale type of topography. These facts are of service in tracing a shale bed throughout a property.

Examination of Soft Clay Deposits. — The principal difference between deposits of shales and of soft clays, so far as the present connection is involved is (1) that shales vary little in thickness and associated rocks as compared with soft clays; and (2) that shale beds can be followed down under overlying rocks, while most beds of soft clay terminate as soon as hard rock is struck either in the bottom or the sides of a deposit. The only prominent exceptions to this rule are the Cretaceous and Tertiary

clays of the coastal plain (see pages 238, 239), for though these are soft clays, they are quite regular in thickness and associated strata.

In dealing with deposits of soft clays, therefore, greater irregularity of form may be expected than when shales are in question, and the work of exploration and examination must be carried on with accordingly greater care.

The forms which clay deposits may take are infinite, but two general types may be expected to occur more frequently than the others. These are the bench and the lens. Clays which are deposited along stream or river banks usually occur in the first of these forms, as distinct benches or terraces (see pages 233, 234, and Figs. 31, 32). Clays which have been found in lakes usually occur in the second form.

Dealing with Known Deposits. — If the area occupied by the clay deposit is small and fairly well known in advance, it will be

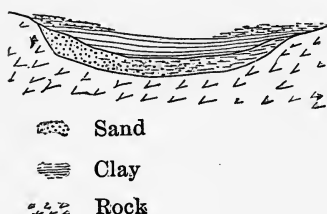


Fig. 36. — Basin or lens, shaped clay deposit.

sufficient to lay it off in squares 25, 50, or 100 feet on a side; determine the elevations at the corners of these squares, and then drill or sink a test pit at each corner. The results of the borings or pits are then to be plotted so as to give two series of cross sections across the deposit at right angles to each other. This is a purely mechanical performance, and little except care

is required to carry it out. It is sufficient only in dealing with small deposits, or when the general form, extent and character of the deposit is already well known. Such cases will arise when a brick plant acquires property adjacent to its own clay pits, when new openings are to be run in on a well-known "vein" of fire clay, and in other similar circumstances.

For such work it is rarely necessary to lay off the squares with a transit and tape, or to determine altitudes with a Y level. In many cases a pocket compass and pacing will suffice to give direction and distance, while a Locke level can be used for elevation. If the case requires more refinement, the "drainage" and "architects'" levels made by different makers are sufficiently precise for such work and will probably be the best instruments to use.

METHODS OF BORING.

The earth auger is usually the best and cheapest instrument for determining the thickness of clay deposits and securing samples of the clays at various depths. It consists of an auger attached to one or more lengths of coupled pipe, the upper length of pipe being provided with a T handle. The auger is sunk by turning the handle, and on withdrawing it a sample of the clay is caught on the auger screw. The use of this implement is limited to the clays proper or to very soft shales.

Two very detailed descriptions have appeared of work done with the earth auger, and as the two accounts taken together cover very fully the entire range of exploratory work that can be handled economically by the use of the auger, they will be quoted almost in full.

The Auger in Light Work. — Mr. Charles Catlett has made extensive use of the earth auger in testing brown ore deposits occurring interbedded with clays and sands at rather shallow depths. His description* of outfit and results is as follows:

1. An auger bit of steel or Swedish iron, with a steel point, twisted into a spiral, with an ultimate diameter of 2 inches, and an ultimate thickness of blade of not less than $\frac{1}{4}$ inch. The point is found more effective when split. The length of the auger proper was gradually increased until about 13 inches was reached as the apparent maximum which could be used effectively. The 13-inch auger contains four turns. This was welded to the end of 18 inches of 1-inch wrought-iron pipe, on which screws were cut for connection.

2. One foot of $1\frac{3}{8}$ -inch octagonal steel, with a 2-inch cutting face, which is likewise welded onto 18 inches of pipe, cut for connections.

3. Ten feet of $1\frac{1}{4}$ -inch iron rod, threaded at either end for connection with 1-inch pipe. When connected with one of the drill bits this becomes a jumper for starting holes through hard material. It is also used when desired to give additional weight to the drill in going through rock below the surface.

4. Sections of 1-inch pipe and connections.

5. An iron handle, with a total length of 2 feet, arranged with a central eye for sliding up and down the pipe and with a set screw for fastening it at any point.

6. A sand pump, consisting of 1 or 2 feet of 1-inch pipe, with a simple leather valve and a cord for raising and lowering it.

* Trans. Am. Inst. Mining Engrs., vol. 27, pp. 127, 128.

7. Two pairs of pipe tongs or two monkey wrenches, with attachments for turning them into pipe tongs.

8. Sundries: 25 feet of tape, oil can, flat file, cheap spring balance, water bucket, etc.

The auger is used by two men, who, standing on opposite sides, turn it by means of the handle. The handle is also useful in giving a good purchase for starting the auger from the bottom of the hole, in opposition to the air pressure, which is considerable. Enough water is continually used to just soften the material. Usually the auger brings up a small portion, which is dry and unaffected. Every few minutes, as the auger becomes full, it is lifted out, scraped off, and replaced. The handle is moved up and tightened by means of the set screw as the auger goes down. At every slight change of the material the depth and the character of the material are recorded.

When hard material is encountered the auger bit is screwed off and the drill bit screwed on, thus forming a churn drill, which may be used for passing through the hard material, the auger being replaced when softer material is reached. The churn drill is used by lifting it and letting it fall, turning it slightly each time. Its weight makes it cut quite rapidly. When the drill is used the muck is either worked stiff enough to admit of its being withdrawn with the auger, or it is extracted by means of the sand pump or a hickory swab. In either case the material is washed and a sample is obtained of the stratum through which the drill is cutting.

Of course the best work with such tools is done on soft material, but it is entirely practicable to go through hard material (a few feet of quartzite or flint, and many feet of ore being often encountered in a single hole), and the ability of this simple contrivance to go through interbedded layers of hard and soft substances makes it very efficient.

The cost per foot increases considerably with depths exceeding 50 feet, but at the greatest depth I attained (some 80 feet) I did not reach either its capacity or the limit of its economical use as compared with other methods.

Up to 25 feet two men can operate it; from 25 feet to 35 feet three men are necessary; from that to 50 feet a rough frame, 15 feet to 20 feet high (costing something over \$1.00), for the third man to stand on, is required. The frame can be moved from point to point. Above 50 feet it is generally necessary to take off one or two of the top joints each time the auger or drill is lifted.

A.	Feet.
Sand and gravel.....	2
Yellow clay.....	2
Clay with some ore.....	4
Solid ore.....	5
White clay and ore.....	3
Total thickness.....	16
Sunk by two men in ten hours.	

B.	Feet.
Loose dirt.....	3
Blue clay.....	7
Shale ore.....	3
Wash ore.....	9
Shale ore.....	3
Wash ore.....	15
Total thickness.....	40
Sunk by two men in eleven hours plus three men for four hours.	

C.	Feet.
Yellow clay.....	12
Black flint.....	$\frac{1}{2}$
Yellow clay.....	$2\frac{1}{2}$
White sand.....	1
Solid sandstone.....	2
Total thickness.....	18
Sunk by two men in five hours.	

D.	Feet.
Sand and gravel.....	1
Clay.....	28
Total thickness.....	29
Sunk by two men in five hours.	

E.	Feet.
Yellow Clay.....	14
Solid ore.....	3
Clay.....	1
Ore.....	$5\frac{1}{2}$
Clay.....	$2\frac{1}{2}$
Total thickness.....	26
Sunk by two men in six hours.	

F.	Feet.
Sand.....	1
Shale ore.....	4
Clay and sand.....	9
Sandstone.....	5
Total thickness.....	19
Sunk by two men in $8\frac{1}{2}$ hours.	

G.	Feet.
Red clay and sandstone.....	19
Clay.....	31
Clay and flint.....	2
Total.....	52
Two men fifteen hours plus three men four hours.	

H.	Feet.
Sand and boulders.....	12
Clay and ore.....	19
Clay and flint.....	3
Clay and a little ore.....	19
Clay and much ore.....	2
Clay and a little ore.....	5
Clay.....	3
	63
Two men for five hours plus three men for twenty-five hours.	

	Ft.	Hrs.	Ft. per hour.
A.....	16	20	0.80
B.....	40	34	1.18
C.....	18	10	1.80
D.....	29	10	2.90
E.....	26	12	2.17
F.....	19	17	1.12
G.....	52	42	1.24
H.....	63	85	0.74
	263	230	1.14

The Auger in Heavy Work. — The most extensive use to which the auger has been put in testing clay deposits was probably in the course of the examination of the Hudson River clay deposits carried out some years ago by Mr. C. C. Jones. In this work most of the holes were deep — 40 feet or more — while some reached over 100 feet. This necessitated certain modifications both in outfit and in the conduct of the work, as is shown in the following description quoted from Mr. Jones' paper* on the subject.

In this work each drilling gang was supplied with one 20-foot hoisting gin, one 6-inch block and fall, 100 feet of $\frac{3}{4}$ -inch rope, 1 differential chain block, two 1 or 2-inch augers, two handles, three pipe wrenches, 12 feet of $1\frac{1}{4}$ -inch iron rod, 102 feet of $\frac{1}{2}$ -inch and inch pipe, in 6 and 12-foot sections, from 20 to 50 feet of $1\frac{1}{4}$ or 3-inch pipe for casing, 1 rock drill, chains, etc. The portable hoisting gin was arranged to fold together so as to be used as a platform on which to carry all the pipe, supplies, etc., which were lashed to it by rope. The gin, thus loaded, could be carried by four men. Each drill gang consisted of three men, and the foreman of a group of gangs aided when shifting position.

The holes varied in depth from a few feet to over 100 feet. In all, about 150 holes were sunk, each gang averaging one hole per day for the entire time.

The gin is made of three pieces of good timber — spruce preferably — 4 inches by 4 inches by 20 feet in size. The top of each piece is chamfered and a bolt is inserted to prevent splitting. The middle piece is, of course, chamfered on two sides, and the others on the inside only. This is to allow for the spread of the legs of the tripod, or gin, when it is set up. On the chamfered face, below the bolts, a hole is bored in each piece for a $\frac{3}{4}$ -inch round iron bar to pass freely. The tops of the three timbers, or legs of the gin, are placed together; the bar is inserted through the hole in the first leg, through one eye of the bail, through the hole in the middle leg, through the other eye of the bail, and then through the hole in the third leg. One end of the iron bar is provided with a squared head, and the other with a slot, into which a pin or dowel is driven, after inserting the bar through the third leg. The bail, of $\frac{3}{4}$ -inch round iron, thus hangs on the bar in the spaces between the legs of the gin. The "drop" of the bail should allow it to pass freely over the top of the middle leg, i.e., the length of the bail

* Trans. Amer. Inst. Mining Engrs., vol. 29, pp. 40-83.

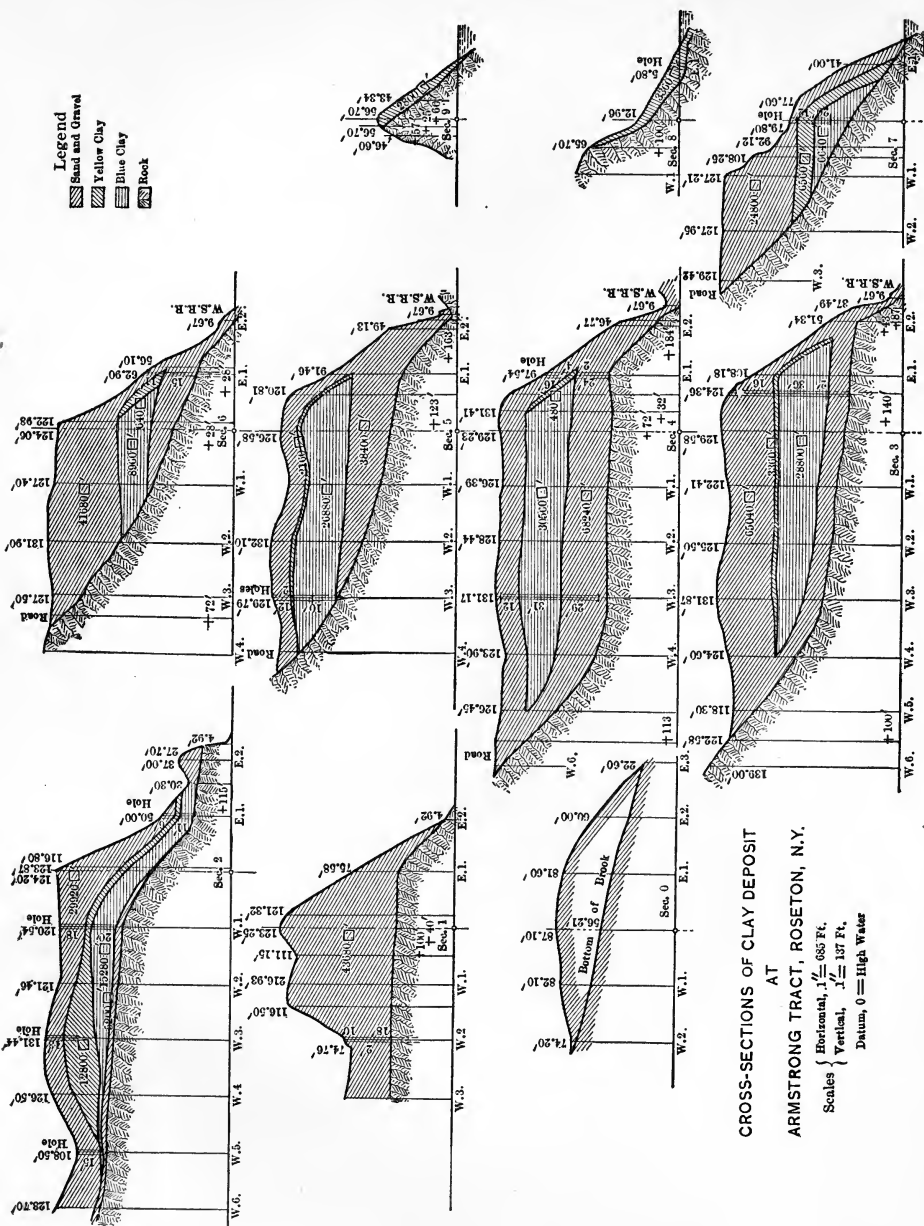


Fig. 37. — Examination of terrace clay deposits. (C. C. Jones.)

should exceed the distance from the bar to the top of the timber. Sufficient play should be given in all these parts to have them fit loosely, and washers should be used to protect the wood.

Cleats are nailed to the middle leg of the gin to form a ladder to the top when erected. To erect the gin the middle leg is turned about the bolt as a hinge, until it again lies on the ground. Three men grasp each a leg of the gin, and by pushing towards the bail raise it in a minute. This single maneuver suffices to erect the gin over an exact point. To dismount it the middle leg is simply carried out until the gin is lowered to the ground; this leg is swung back over the bolt again and thus forms the platform upon which everything is carried forward by a single trip, as above described, to the next point of operation. As soon as the gin has been erected, one man ascends the ladder and hooks the wooden block over the bail, and the fall is plumbed over the exact point for the bore hole. This is an important particular, to insure always a vertical stress in withdrawing the auger. The rope and fall are now caught up on one of the cleats to the side. The auger is made from an ordinary wood auger with 2-inch cutting face, which is welded to a short piece — about 18 inches — of black pipe, on one end of which a thread is cut. This makes the bit about 3 feet along. The handle is about 2 feet long over all, and is made of two pieces of $\frac{3}{4}$ -inch round iron, welded to a strong cylindrical ring, which will pass freely over couplings for 1-inch black pipe. The ring is provided with a strong $\frac{5}{8}$ by $2\frac{1}{2}$ -inch set screw, for securing the handle to the pipe. The differential chain block is Yale and Towne's $\frac{1}{4}$ -ton capacity, single-chain. Stillson pipe wrenches are used, two 18-inch and one 14-inch, and a small monkey wrench is required for the set screw. The section of $1\frac{1}{4}$ -inch iron rod has threads cut at each end for 1-inch pipe couplings. The five 12-foot sections and seven 6-foot sections of 1-inch pipe have threads cut at each end for couplings. Each section is provided with a coupling at one end, and it is good practice to have a string of extra couplings on hand.

The $1\frac{1}{4}$ -inch or 3-inch pipe for casing is in 4-foot or 5-foot sections, with threads cut at each end for couplings. This casing is driven down when troublesome sand or gravel is encountered near the surface. As a rule it is little employed; but in some localities it is an absolute necessity. The drill is 18 inches long with a 2-inch cutting face, and a thread cut at the other end for 1-inch couplings. It is made from $1\frac{1}{4}$ -inch octagon steel. The chains, of $\frac{3}{8}$ -inch iron, with short links, are 3 feet long, and have heavy rings at one end and hooks at the other. An oil can and a small file, both for couplings, about complete the outfit for each boring gang.

In addition to this, a single outfit complete, exactly like the foregoing, but made of $\frac{1}{2}$ -inch pipe, the auger and drill having

1-inch cutting face, will be found indispensable. This can be taken from gang to gang as required. It sometimes happens that a bore hole made by the larger apparatus becomes unexpectedly obstructed (say, at 50 to 70 feet) by a pebble, a coupling accidentally dropped in, or some other unfortunate cause, and all efforts at progress fail. This smaller apparatus can then often be successfully employed to pass the obstacle and complete the test.

In commencing operations, an auger is attached to a 12-foot section, the handle is adjusted, and boring is begun at a designated point, great care being taken to start vertically, and to preserve the original orifice. Neither more nor less than five turns of the auger are required. This fills the bit, which is then drawn to the surface. One man is always required to attend to the bit, as it enters or emerges from the hole — an insignificant but important duty. As the hole deepens additional sections are attached, until the assistance of the gin is required. At this period, after the auger has received the prescribed number of turns, the set screw in the handle is loosened and the handle is allowed to drop to the ground. A 3-foot chain is passed around the pipe, the hook being passed through the ring to form a running noose; the hook is attached to the fall, and stress is applied. After lifting the pipe to a convenient height it is gripped at the ground, either with a wrench or by simply tilting one end of the handle so that the ring binds against the pipe. The stress is released on the chain as soon as the pipe is held by the grip and the chain slipped down for a fresh hold, continuing in this manner until the auger has been completely extracted. When the depth reaches 30 feet, the column of pipe must be disconnected at that point. To expedite this procedure, a 3-foot chain is looped, hook and ring, and loosely dropped around the top of the gin. As the pipe is withdrawn from the hole it is so directed at the top as to enter this loop. After withdrawing the six sections as above described, the handle is attached again below the lowest coupling (where it already lies in place), the 30-foot length is unscrewed, and being held upright by the loop at the top of the gin is merely set at one side. The chain on the fall is again attached to the pipe above the handle, a stress applied to the rope, the handle loosened as before, and this process is continued for each 30-foot length until the auger has been withdrawn from any depth; the invariable rule being to have always either the handle or the chain under stress below a coupling attached to the pipe, while the auger remains in the hole. This operation is reversed to lower the pipe again into the hole, i.e., the sections are replaced in the order of their removal. It follows that the depth of the hole at any time can be ascertained from the number of sections in use. At depths exceeding 75 feet (frequently less), the chain block must be used to start the auger, hooking it on

to the wooden fall when required. In this manner, with a little training and a proper division of the duties of each man in the gang, the boring becomes practically continuous, and proceeds very rapidly. One hundred feet of pipe can be started, pulled up, disconnected, the auger bit cleaned, and the whole apparatus let down into the hole again in a few minutes.

When sand is encountered, enough water to make it adhesive must be poured into the hole, and the auger will then carry it to the surface. Thin strata of sand cause difficulty, and, similarly, fine gravel is frequently impenetrable. For holes of this size the various sand-pump devices are failures, and the auger alone will do the work better. The drill, with or without the iron-rod section, offers the readiest solution to the gravel question. Gravel must be broken up or pushed to one side. The knack of manipulating the drill to meet these circumstances can only be imparted by experience. The best plan is to instruct practically the foreman alone, who must then deal personally with the difficulty when it arises.

Quicksand is another great obstacle to deep boring. If the quantity of water is small, and the stratum thin, it is occasionally possible to penetrate it by very rapid work, and bore to the depth required for a given purpose; but a thick seam is impenetrable by the auger, on account of the closing up of the hole through the vacuum created by withdrawing the auger, or by the pressure of superincumbent masses. Casing will not overcome this difficulty. Ordinarily, and especially in test boring in clays, it is unnecessary to penetrate quicksands.

A long chapter could not fully treat the subject of accidents. A general rule other than an exhortation to patience is out of the question, because of the variety of these seemingly trifling mishaps. Grappling devices to remove accidental obstacles in a bore hole are all excellent in theory, but the simplest devices often succeed where the more elaborate fail. A section of pipe becoming disconnected in the bore hole can be caught up by using the disjointed member provided with a clean, freshly-oiled coupling; a coupling can often be removed from a hole by using a taper-pointed stick driven into the end of the pipe; an auger broken at the shank may be grasped by a noose of short-link chain lowered by two strings, which is then grappled by a hook on the end of the $\frac{1}{2}$ -inch rod or pipe, or entangled around the small drill. Most of the mishaps happen through neglect of the simple rules given. It is important always to avoid gorging the auger at great depths. It is apt to be frequently clogged at the bottom of a long column of pipe, and it is not advisable to then reverse the auger to release it.

References on Methods of Field Examination. —

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Determination of Composition and Tonnage.

Errors in Sampling. — In sampling clays from a natural outcrop, or even from an artificial cut which has stood for any length of time, it must be borne in mind that there are two distinct opportunities for serious error.

The first is due to purely physical causes, and arises from the very yielding nature of clays when exposed for a time to atmospheric action. Parts of the face of the outcrop or cut are likely to have slipped down considerably, so that the exposure does not represent the true character of the clay.

The second chance for error arises from the fact that, when clays or shales are exposed to the action of rain or surface waters for any length of time, the surface clay will be robbed of its more soluble or changeable constituents. The outcrop is, therefore, likely to show lower percentages of lime, magnesia, alkalies and sulphur than the same clay body carries in depth. A sample taken from the outcrop might, on analysis, show a refractory clay practically free from these fluxing constituents, while ten or fifteen feet below the outcrop the fresh clay might contain so much lime, alkalies, etc., as to be of very inferior grade. The analyses quoted below illustrate very clearly the differences which may be expected to occur between fresh unweathered clay and the clay as it outcrops. Both the analyses quoted are of clays from Croton Point, New York.

It will be seen that the blue unweathered clay (A) contains more than twice as much lime as the yellow weathered clay (B). Weathering has also slightly reduced the magnesia, and has affected the alkalies very markedly. The insoluble constituents — silica, alumina and iron — are in consequence of this leaching, relatively increased in the weathered clay.

	A.	B.
Silica (SiO_2).....	51.61	56.75
Alumina (Al_2O_3).....	19.20	20.15
Iron oxide (Fe_2O_3).....	8.19	8.82
Lime (CaO).....	7.60	3.14
Magnesia (MgO).....	1.25	1.20
Alkalies (K_2O , Na_2O).....	5.32	4.50
Carbon dioxide (CO_2) }	7.25	5.52
Water.....		

Estimation of Tonnage. — On the pages immediately following several long series of tests of the specific gravity and weights of a large number of clays and shales are quoted and discussed. From the data there given the following rules can be considered safe:

(1) Ordinary soft clays will average 120 pounds per cubic foot, or 3240 pounds per cubic yard, in the bank.

(2) Shales will average 150 pounds per cubic foot, or 4050 pounds per cubic yard.

For rough calculations as to tonnage, it may, therefore, be assumed that clays will weigh $1\frac{1}{2}$ tons, and shales 2 tons, per cubic yard.

Prof. G. H. Cook, in 1874, determined* the specific gravity of a large series of clays from New Jersey. In making this determination "a prism about an inch in length was cut out of the solid mass. This was covered by a film of paraffin and weighed, first in air, then in water." The values thus obtained are, therefore, close approximations to the density of the clay as it occurs in nature, and when multiplied by 62.4 will give the weight per cubic foot of the product in the bank. The values varied from 1.539 to 2.170, the average of the 86 samples of unwashed clays being 1.824. Converted into pounds per cubic foot, these values are as follows:

	Specific gravity.	Pounds per cubic foot.
Maximum.....	2.170	135.41
Average.....	1.824	113.82
Minimum.....	1.539	96.03

* Report on the Clay Deposits of New Jersey, 1878, pp. 283-286.

Part of this great variation in density was due to the variations in furnaces, etc., but much of it was directly traceable to the varying percentages of sand contained in the clays. The table following illustrates this point.

TABLE 113. — RELATION BETWEEN SPECIFIC GRAVITY AND SAND PERCENTAGES. (Cook.)

Specific gravity.	Per cent of sand.	Specific gravity.	Per cent of sand.
2.321	58.40	1.607-1.612	8.60
2.283	57.10	1.743-1.789	6.51
2.052-2.101	56.80	1.657-1.705	3.10
2.047-2.077	48.40	1.764-1.769	1.10
1.981-2.023	40.50	1.766-1.893	0.80
1.971-2.138	39.95	1.528-1.542	0.71
2.012-2.022	37.85	1.738	0.70
2.129-2.151	37.10	1.731-1.809	0.50
1.994-2.047	28.81	1.578-1.610	0.50
1.705-1.732	27.80	1.723-1.742	0.20
1.861-1.864	20.60		

In 1896 Wheeler reported the specific gravities of a series of 153 Missouri clays, of several widely different types. His results, grouped by classes, are given in the following table.

TABLE 114. — SPECIFIC GRAVITY OF MISSOURI CLAYS. (WHEELER.)

Type of clay.	Specific gravity.		
	Minimum.	Average.	Maximum.
Kaolins (residual).....	1.69	1.90	2.02
Loess clays.....	1.69	2.05	2.17
Gumbo clays.....	1.98	2.01	2.05
Tertiary clays.....	1.93	2.03	2.13
Fire clays (shales).....	2.23	2.40	2.54
Nonrefractory shales.....	2.15	2.38	2.56

In recent clay investigations* carried on by the New Jersey Geological Survey a series of 31 clay samples were tested for specific gravity. In this case the clays were powdered, and the specific gravity was then determined by the use of the pycnometer. Since this method disregards the air spaces in the clay, and really gives the specific gravity of the mineral particles, the results, as might have been expected, gave much larger values than

* Vol. VI, Reports New Jersey Geol. Survey, p. 115, 1904.

those reported by Cook. The minimum specific gravity found was 2.39; the highest, 2.84; while the average for the 31 samples was 2.584.

A similar series of 32 Iowa clays gave* a minimum value of 2.25; a maximum, 2.64; and average, 2.46.

For the purposes of the engineer or manufacturer, these Iowa and the later New Jersey attempts to determine the "true specific gravity" of clays may be disregarded entirely; for the values found by this method are not of the slightest economic importance. Neither engineer nor manufacturer has any interest in knowing the "true specific gravity" of a clay in a state of theoretically maximum density, free from all air spaces; for such clays do not occur in nature. What we do want to know is the weight per cubic foot of clay as it occurs in the clay bank, and fortunately the older work of Cook and Wheeler gives the desired information.

The two sets of results (Cook and Wheeler), when combined and divided merely into the two natural groups of (1) ordinary clays and (2) hard shales, give the following results:

TABLE 115.—SPECIFIC GRAVITY AND WEIGHT OF CLAYS.

Kind.	Specific gravity.			Weight in pounds per cubic foot.		
	Mini- mum.	Aver- age.	Maxi- mum.	Mini- mum.	Aver- age.	Maxi- mum.
Clay.....	1.539	1.90	2.17	96	118.6	135.4
Shale.....	2.15	2.39	2.56	134.2	149.1	161.7

These figures may, therefore, be used in calculations. For convenience it may be considered, without sensible error, that a cubic foot of clay, in the bank, will average 120 pounds, while a cubic foot of shale will average 150 pounds.

* Vol. XIV, Reports Iowa Geol. Survey, p. 116.

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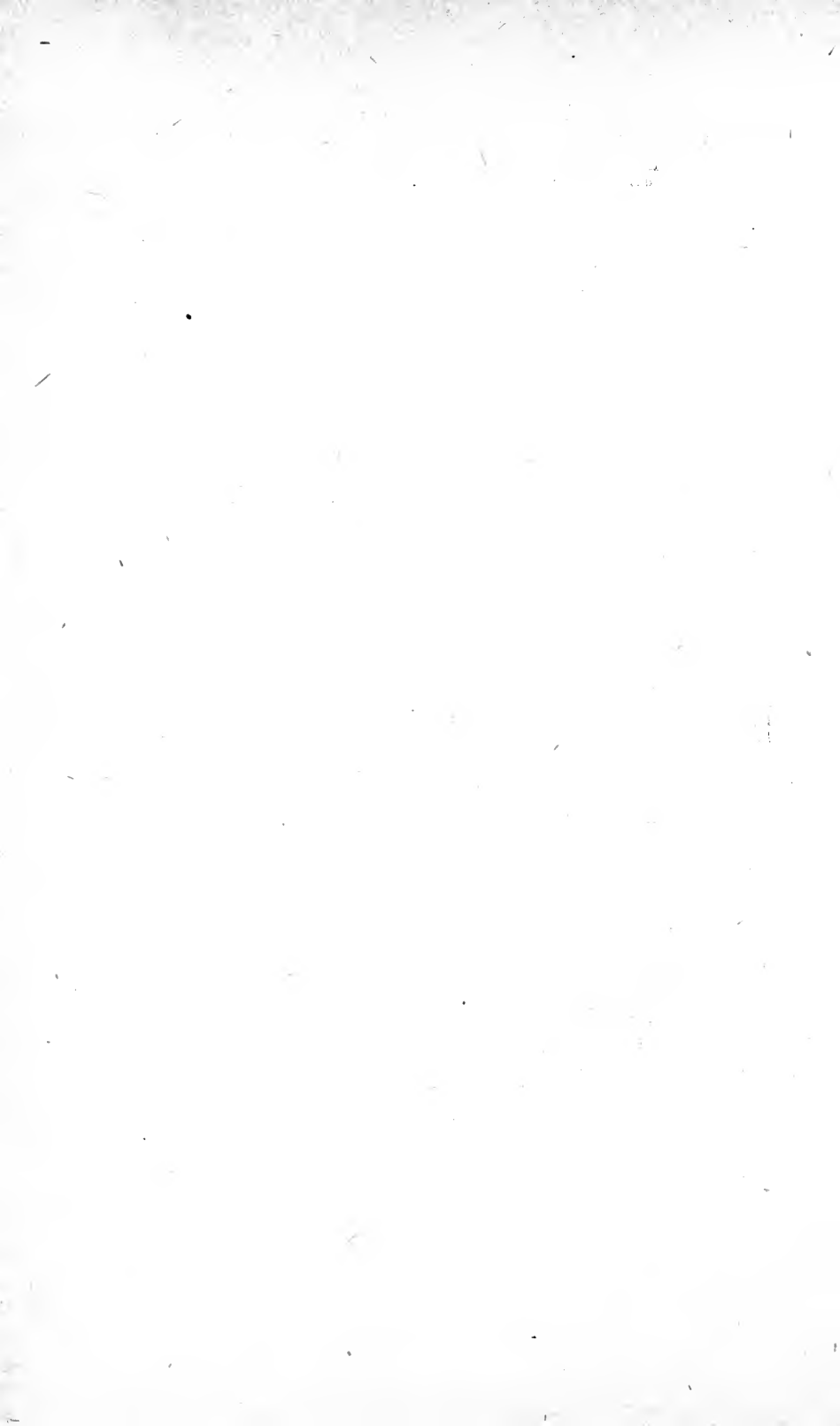
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